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UNDERSTANDING AIRFIELD CAPACITY FOR AIRLIFT OPERATIONS

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PREFACE

The Mobility Division of the Directorate of Forces, Headquarters, U.S. Air Force, and the Force Projection Directorate in the Office of the Secretary of Defense requested that RAND develop a method that improves on the traditional maximum (aircraft) on ground (MOG) measure of airfield capacity. Subsequently, the Force Projection Directorate requested that the method be refined and its automation improved. This report responds to those requests.

In the spring of 1994, the Office of the Secretary of Defense was coordinating the Airlift Requirements Study, in which a simulation model developed by the Air Force was to be used to analyze alternative fleets of passenger and cargo aircraft. However, certain model inputs had been criticized, especially in the earlier C-17 Cost and Effectiveness Analysis, for contributing to model-generated estimates of airlift capacity that were "too optimistic" and for "overestimating" the ability of the airlift system to move forces and supplies into overseas theaters of operation. The desire for more-realistic inputs describing airfield capacities led to the first RAND study.

That research, led by Ruth Berg, and a companion effort,[1] led by Paul Killingsworth, constituted the study "Enhancing the Effectiveness of Mobility Forces," which produced an initial version of the Airfield Capacity Estimator (ACE). That version was distributed in the fall of 1995 to several organizations at the Office of the Secretary of Defense and the Air Mobility Command, and was subsequently used at RAND in support of the Strategic Airlift Force Mix Analysis and the C-17 Tactical Utility Study.

Follow-on work, led by James Stucker and sponsored by the Force Projection Directorate in the Office of the Secretary of Defense, investigated how differing levels and distributions of airfield resources, over a set of airfields, can affect airlift throughput. That research resulted in substantial improvements to the ACE model. This report documents the logic, implementation, and initial applications of this revised version of ACE. Naturally, the revised model owes much to the initial work. Software for the ACE model, described in this report, is available on the RAND homepage at http://www.rand.org/publications/MR/MR700/ACE/.

[1]See P. Killingsworth and L. Melody, *Should C-17s Be Used to Carry In-Theater Cargo During Major Deployments?* Santa Monica, CA: RAND, DB-171-AF/OSD, 1997.

The initial work was carried out in the Force Structure and Modernization program within Project AIR FORCE and in the Forces and Resources Policy Center within the National Defense Research Institute (NDRI). The follow-on work was conducted within the Forces and Resources Policy Center. Project AIR FORCE is a federally funded research and development center (FFRDC) that performs studies and analyses under sponsorship of the United States Air Force; NDRI is an FFRDC sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

This report should be of interest to deployment planners, and to air mobility resource programmers and managers.

CONTENTS

FIGURES

TABLES

SUMMARY

What is the capacity of an airfield—how many aircraft can it service in a day? The realistic answer must be, "It depends." It depends on the usability of different areas of the airfield for parking different types of aircraft, on the changing mix of cargoes the aircraft carry (and, hence, the times needed to on-load or off-load), on the distances from the previous airfield and to the next airfield (and, hence, the fuel needed), on whether transiting aircraft make quick stops or need extended ground time (e.g., for crew rest), on whether the airfield operates with peacetime levels of manning and equipment or is augmented with additional resources, and on many other factors. Moreover, as an airfield services more of one type of aircraft, the fewer aircraft of other types it can handle. Thus, an airfield's capacity is not a single number but a *set* of numbers.

RECENT MEASURES OF AIRFIELD CAPACITY

Over the past dozen years, the DoD's major mobility studies have shown slight but increasing emphasis on airfields. For example, the Revised Intertheater Mobility Study (RIMS) of the late 1980s considered sortie-per-day constraints at destination airfields, based on the numbers of parking spaces available and the time each aircraft spends on the ground being serviced and having its cargo off-loaded. Parking (or MOG, the maximum on ground) was expressed in C-130–equivalents for each airfield, and ground times were specified for narrow-body (C-141 and C-17) and for wide-body (C-5 and KC-10) aircraft, yielding separate capacities for wide-body aircraft and for narrow-body aircraft, for each airfield.

The Mobility Requirements Study (MRS) in the early 1990s used much the same procedure but considered enroute, recovery, and destination airfields. It expressed MOG in C-17–equivalents. Both RIMS and the MRS considered parking as the ultimate airfield constraint: Other ground resources could and would be augmented until they were not constraining, but parking was fixed, at least within the time frames considered in the studies.

Separate MOG and fuel constraints became of interest as the MRS Bottom-Up-Review Update in 1994, as well as the more recent Airlift Requirements Study and Strategic Airlift Force Mix Analysis, considered these constraints. These studies used the Air Mobility Command's Airlift Flow Model, a simulation of aircraft, aircrews, and airfields, to estimate airlift capabilities and needs, so the MOG was used directly in

the parking events rather than as a parameter in an analytic sorties-per-day calculation. These studies used different ground times for each aircraft type (six military aircraft and four commercial aircraft) and for each "type" of stopover (on-load, enroute, off-load without recovery airfield, and off-load with recovery airfield). Because each airfield was used for only one type of stopover, 10 capacities resulted (each the lesser of a MOG-based capacity or a fuel-based capacity) for each airfield.

OUR APPROACH

We formalize and generalize the approach implicit in the earlier studies. We define the basic relationship between airfield resources and the airfield's capacity as

$$C = \mathrm{Min}\left(\mathrm{R}_i * \mathrm{A}_i / S_i\right) \quad \text{over } i = 1, \ldots, \mathrm{n} \tag{S.1}$$

where C stands for the capacity of the resources at a particular airfield expressed as the number of aircraft assigned a particular mission that can be serviced in one day. R_i represents the quantity of a particular resource i available at the airfield. A_i represents the hours per day that resource is available to support airlift operations. And S_i stands for the time required of the resource i in servicing one aircraft.

If parking is the only (or the only constraining) resource, capacity can be expressed as

$$C = \frac{\text{MOG} * \text{working hours}}{\text{standard ground times}} \tag{S.2}$$

which was the relationship used in the RIMS and MRS studies.

Our approach goes much deeper. From our visits to over a dozen airfields and interviews with scores of service personnel and technicians, we have identified over 40 types of resources (the i's in Eq. S.1) that contribute significantly to airfield capacity and that can, when in short supply, constrain that capacity. Even so, we do not attempt to model all airfield resources.[2] For the three most significant functional areas—aircraft servicing, fueling, and loading—we model both an aggregate resource—the package, or unit type codes (UTCs), of skills and equipment the Air Force regards as necessary to perform those functions—and we model the individual resources that experts have identified as being especially (or most visibly) associated with airfield capacity: ground-power units, fuel trucks, k-loaders, etc. For three other areas—air-traffic control, ground control, and aircrew servicing—we model only the aggregate resources. These procedures are now embodied in a personal-computer-based model called the Airfield Capacity Estimator (ACE).

[2]Nor do we force the user to obtain or make up data on all the resources that are modeled. Any resource for which the user has no information or no interest can be set to 9999 and the model will consider it to be in unlimited supply.

ACE is implemented as a Microsoft Excel application. Running on Macintosh- and IBM-compatible microcomputers, it estimates resource service times, aircraft ground times, resource capacities, and the overall capacity of airfields for servicing aircraft assigned up to six different mission types and two ground-servicing profiles.

ACE relates aggregate and specific resources to some 17 ground-servicing operations:

- block in
- post-flight, through-flight, and pre-flight inspections
- general, nitrogen, and oxygen servicing
- repair
- passenger and cargo off-loading and on-loading
- pre-fueling, fuel transfer, and post-fueling
- de-icing
- block out.

We use average times (by aircraft type) for eight of these operations, assuming that their duration and resource demands vary little over missions and over airfields. The other nine are treated in one of two ways. For five of them—fueling (transfer) and passenger and cargo on-loading and off-loading—we calculate specific times for each mission at each airfield by accumulating times for particular tasks—e.g., driving a fuel truck to the aircraft, hooking up, loading one pallet onto a k-loader, or moving one pallet from the k-loader onto the aircraft. This allows us to identify and quantify aircraft delays when resources are limited or distances are long. That is, when fueling and loading are involved, aircraft ground time depends on the level of airfield resources, as well as on the type of aircraft, the type of stopover, and the particular ground operations specified for the stopover.

The times for the remaining four operations—nitrogen servicing, oxygen servicing, repair, and de-icing—do seem to vary widely for different aircraft types, by type of stopover (mission), and for individual aircraft landings. The model handles this variability in either of two ways, at the user's direction. First, the run can use expected-value calculations to estimate average resource-use times, aircraft ground times, and airfield capacities. This process does not yield the true "expected value" of capacity, because both the service-time equations and the capacity equations are nonlinear. However, in all the cases we have tested, it yields a close approximation to that value—and it is quick.

Alternatively, the user can specify that ACE conduct Monte Carlo experiments—drawing values (for each aircraft in each mission) for the four time-varying operations just discussed from empirically derived distributions of past times. The random draws for each set of missions can be iterated 10, 20, or even 500 times, producing representations of the output distributions for use times, aircraft ground times, and airfield capacity. This output reminds the planner that some exceptionally long and some exceptionally short repair times will occur at least

occasionally. Given valid data, the Monte Carlo method produces "better" estimates than the expected-value approximation, but it takes substantially longer. Details on both procedures can be found in Appendix C.[3]

Developed for purposes of research and demonstration, the current implementation of ACE does not represent a "production-ready" software package. As with other models developed at RAND for research purposes, sponsoring agencies or others may elect to further develop the ACE model, perhaps extending it to consider additional detail or additional airfield functions, to check users' input data more extensively for errors and inconsistencies, to be more convenient and easy to use (e.g., through access to standard data files and databases, etc.), to operate in tandem with models of airlift and tanker flows through multiple airfields, and so on.

The major limitations of the current implementation are that it uses (a) questionable and single-valued representations of resource availabilities for material-handling equipment—especially k-loaders and wide-body elevator loaders—and (b) limited and dated information on aircraft-repair frequencies and durations. Nevertheless, in evaluations and comparisons made to date, ACE's estimates of airfield capacities appear to be reasonable and consistent with experts' expectations. Since airfields seldom operate in peacetime at full capacity and since appropriate historical data are not available, we have not been able to compare ACE's estimates with airfields' actual throughputs. Efforts to validate and refine the model should continue.

FINDINGS AND RECOMMENDATIONS

Our estimates of aircraft ground times and airfield capacities, based on the currently available data documented in this report, suggest wide differences in times and capacities. Those differences are due to many factors, including the following:

- the type of aircraft, the type of stopover, and the number and sequencing of the ground operations
- the physical layout of the airfield—its size, the number of ramps, their locations and distances from the fuel source and from the passenger and cargo terminals—and its hours of operation
- the types and quantities of ground resources available at the airfields and the reliability and maintainability of each resource—hence, its availability for use
- the types of fueling available, the quantity of fuel available, the quantity needed by each aircraft, the number of trucks available, and the distance the trucks must travel
- the types of cargo and the quantities to be off-loaded and/or on-loaded; the number of buses, k-loaders, and wide-body elevator loaders; and the distance they must travel.

[3]The initial version of ACE was implemented using the C programming language, the UNIX operating system, and minicomputers. It produced only expected-value estimates.

We summarize two sets of findings here. The first uses expected-value calculations to illustrate the range of aircraft ground times associated with enroute stopovers and with off-loads at aerial ports of debarkation. The second uses Monte Carlo analyses to illustrate the range of times and capacities associated with several types of missions. Both sets are based on the ground resources and operations at the hypothetical airfield sketched in Figure S.1.

Ground Times Vary by Aircraft Type and Required Operations

The first estimates are shown in Tables S.1 through S.3. Table S.1 contains ground times estimated for stopovers at enroute and destination airfields, where the aircraft undergoes "quick-turn" servicing and fueling and where cargo may be off-loaded.[4] The estimates show the wide range of ground times and, hence, suggest the wide range in capacity that can be associated with any airfield.

RANDMR700-S.1

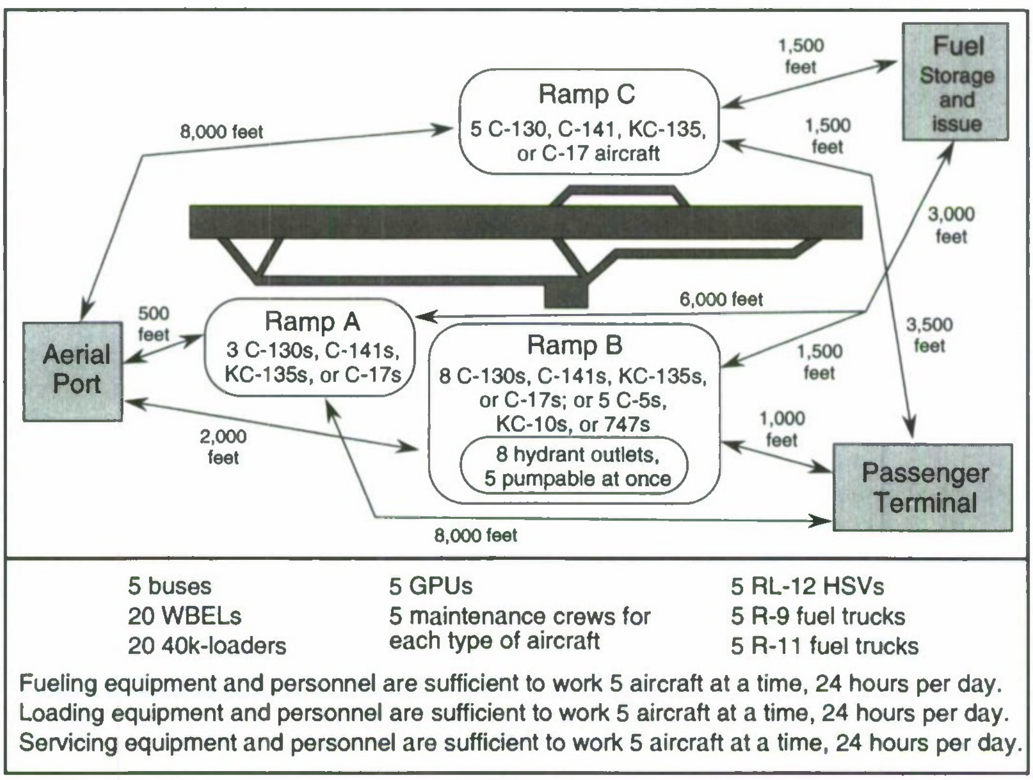

Figure S.1—Airfield Layout for Illustrative Calculations

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[4]Quick turns, usually performed at enroute and overseas airfields, represent one of our ground-servicing profiles. "Full-service" stops, usually performed at the home airfield, are longer.

Table S.1

Ground Times, by Aircraft Type and by Operations Needed: Ramp B (times in hours + minutes)

	Quick-Turn Servicing with . . .			
Aircraft	Fueling	Off-Loading	Both	Neither
C-130	1 + 41	0 + 46	1 + 41	0 + 46
C-141	2 + 50	1 + 42	2 + 50	1 + 42
C-5	4 + 24	2 + 22	4 + 24	2 + 22
C-17	2 + 52	1 + 30	2 + 52	1 + 30
KC-10	4 + 46	2 + 41	4 + 46	2 + 41
KC-135	5 + 11	3 + 05	5 + 11	3 + 05
747	4 + 00	2 + 36	4 + 33	1 + 55

SOURCE: Expected-value computations of ACE. Mission and output screens for "quick turn plus both" for all except KC-135 estimates shown as Figures 6.7 and 6.8.

NOTE: Estimates based on resource levels and availabilities shown in Figure S.1 and Appendix G; hydrant-fueling potential of 500 gallons per minute; and off-loading full load of pallets. For aircraft that can be serviced on several ramps, times shown are for best (lowest aircraft ground times) ramp.

Table S.2 contains the capacity estimates associated with those ground times and with the resources sketched in Figure S.1 and detailed in the appendices. These are "or" capacities: We estimate that this airfield can support 23 C-5 refueling missions per day, or 54 C-17 off-loading missions, or 14 747 fueling and off-loading missions, and so on. ACE can also estimate "and" capacities, in both expected-value and Monte Carlo computations, as we shall see in the discussion of Table S.6.

The estimates in Table S.2 represent the capacities of all the ramps and resources of the airfield, as opposed to the estimates in Table S.1, which represent aircraft ground times specific to ramp B. While ground-power units (associated with the S, or servicing function) usually constrain the airfield capacity, several times the aggregate loading resources (L) do the constraining, twice it is the aggregate fueling resources (F), and once it is ground control (G).

Table S.2

Airfield Capacity (in aircraft per day) and Limiting Resources, by Aircraft Type and Operations Needed

	Quick-Turn Servicing with . . .			
Aircraft	Fueling	Off-Loading	Both	Neither
C-130	42 F	72 L	42 F	80 G
C-141	37 S	62 S	37 S	62 S
C-5	23 S	27 L	23 S	44 S
C-17	36 S	54 L	36 S	70 S
KC-10	21 S	30 L	21 S	39 S
KC-135	21 S	39 S	21 S	39 S
747	26 S	14 L	14 L	55 S

SOURCE: Expected-value computations of ACE. These capacities were calculated in association with the ground-time estimates of Table S.1.

NOTE: Functional area representations include F for fueling, S for servicing (aircraft generation), L for loading, and G for ground control.

Ground Times Vary by Airfield Layout and Resources

Table S.3 contains estimates of the ground times associated with C-17 stopovers at an enroute airfield. These estimates are based on two types of fueling: (a) hydrant fueling, whereby the fuel is piped directly to selected aircraft-parking spaces, and then through a hydrant-service vehicle and into the aircraft; and (b) truck fueling, whereby fuel-tanker trucks transport fuel to dispersed aircraft from a common fuel source. Hydrant fueling is usually faster, because it requires only a single hookup and no waiting for trucks to return from refueling. But modern aircraft can receive fuel from two (or sometimes more) trucks simultaneously, so truck fueling can be faster at airfields with enough trucks.

We saw in Table S.1 that the time required for the basic block in, block out, inspection, and servicings associated with a quick turn of a C-17 is 1 hour and 30 minutes. Fueling lengthens ground times by the times required for hookups, unhookings, and administrative tasks, as well as the transfer of fuel. For hydrant fueling, only one hydrant-service vehicle (HSV) is used per aircraft being fueled, so the number of hydrant-service vehicles does not influence the servicing time. That is, the number of HSVs at the airfield determines the number of aircraft that can be fueled at one time or in a day, but it does not affect the time required for each fueling. At a sustained pumping rate of 500 gallons per minute, the transfer of 150,000 pounds of fuel from a hydrant nearly doubles the C-17's ground time, increasing it to 2 hours and 52 minutes.

The right-hand portion of the table shows the effects on aircraft ground time when hydrants are not available and fuel must be transported to the aircraft by trucks. These estimates indicate that, for this aircraft and this postulated airfield, aircraft ground time is, with one exception, slightly longer with truck fueling than with hydrant fueling, even when many trucks are available. Four trucks remove all truck-associated delays, even when the fill stand is over a mile away. With fewer trucks available, the aircraft ground time is longer, over 6 hours in the most extreme case shown.

Table S.3

C-17 Ground Times, by Fueling Type, by Location, and by Number of Trucks Available (times in hours + minutes)

Hydrant	Trucks	Truck Fueling		
Fueling	at the Airfield	Ramp A	Ramp B	Ramp C
2 + 52	1	6 + 15	5 + 04	4 + 16
2 + 52	2	4 + 05	3 + 35	3 + 14
2 + 52	3	3 + 59	3 + 29	3 + 08
2 + 52	4 or more	3 + 07	2 + 56	2 + 50

SOURCE: Expected-value computations of ACE.

NOTE: Hydrant-fueling estimates based on fuel transfer of 500 gallons per minute. All estimates assume 150,000 lb of fuel required per aircraft, quick-turn ground-servicing profiles, and no on-loading or off-loading of passengers or cargo. Each fuel truck is assumed to be available for work 20 hours per day and to be able to transfer 5,800 gallons of fuel per load.

The availability of material-handling equipment affects the times and capacities for on-loading and off-loading aircraft similarly, but often to a far greater extent. Information we received from the Air Force concerning the "up" time of k-loaders, wide-body elevator loaders (WBELs), and forklifts shocked us: Much of this equipment is apparently so old and so fragile that it spends far more time being worked on than working.

Table S.4 contains estimates of off-loading times and aircraft ground times for C-17 aircraft undergoing pallet off-loading (but no on-loading or fueling) during a quick-turn service. The table shows, for each quantity of 40k-loaders, estimates of the capacity, in aircraft per day, of the airfield, and the limiting resource. Estimates are shown for k-loader inventories from 1 to 27, using a baseline availability of 2.35 hours per day for each loader.

As we would expect with such a low availability rate, many vehicles must be added to the airfield inventory before the aircraft delays associated with waiting for k-loaders can be eliminated and the off-loading times level off (at 34 minutes for aircraft serviced on Ramp A and 33 minutes for aircraft serviced on Ramp B). However—and this would not be obvious without our modeling of ground operations—the aircraft ground time is completely unaffected by the k-loader delays, at least the delays associated with the layout of this particular airfield in Figure S.1: C-17 ground time is constant at 90 minutes per aircraft—the minimum time allowed under the quick-

Table S.4

C-17 Times (in minutes) and Capacities (in C-17s per day), by Number of 40k-Loaders

k-Loaders at the Airfield	Preferred Ramp(s)	k-Loader Time per Aircraft	Aircraft Time for Off-Loading	Aircraft Ground Time	Airfield Capacity	Limiting Resource
1	A	43	49	90	3.3	k-loaders
5	A	43	49	90	16.4	k-loaders
10	A	43	49	90	32.8	k-loaders
14	A	43	39	90	45.9	k-loaders
15	A, B	43 / 52	38 / 44	90 / 90	48.9	k-loaders
16	A, B	43 / 52	34 / 38	90 / 90	51.6	k-loaders
17	A, B	43 / 52	34 / 37	90 / 90	54.3	k-loaders
18	B	52	37	90	48.7	k-loaders
19	B	52	36	90	51.4	k-loaders
20	B	52	36	90	54.1	k-loaders
25	B	52	33	90	67.6	k-loaders
26	B	52	33	90	70.3	k-loaders
27	B	52	33	90	70.4	GPUs

SOURCE: Expected-value computations of ACE.

NOTE: All estimates assume a full load of 18 pallets is off-loaded during quick-turn ground servicing; no passenger operations, loading of cargo, or fueling occur. Each k-loader is assumed to be available for work 2.35 hours per day. In each run, 75 aircraft were requested.

turn protocols.[5] This level of k-loader–caused delay does not affect the ground time of the C-17, because that aircraft is designed for easy and quick on-loading and off-loading. For many other types of aircraft, k-loader (and other types of delays) can directly affect aircraft ground times.

Uncertainties Accumulate to Affect Capacities

Table S.5 contains output from a Monte Carlo analysis of C-17 aircraft assigned a mission involving fueling and off-loading of cargo at the airfield described in Figure S.1. ACE draws values for each of the four probabilistic operations. As shown in the lower portion of the table, nitrogen servicing is assumed to be required in 10 percent of the stopovers, but for these 25 aircraft it "actually" occurred only three times, or 12 percent of the time. Similar deviations occur for oxygen servicing and repair. But the differences in the times when they do occur reveal more information about our inputs and our assumptions. Data we collected for nitrogen and oxygen servicing (and also for de-icing, which is not considered here) suggest that the servicing times are relatively constant, at 15 minutes and 45 minutes, respectively, for the C-17, if the aircraft needs those services. Consequently, those random draws are for the need for servicing. For repairs, on the other hand, we model both the occurrence and the duration as being probabilistic.

This Monte Carlo mode of analysis acknowledges that some aircraft require more servicing than others, even if they are on identical missions; hence, they consume more ground resources; and, hence, we must have the model set aside resources for each aircraft. In the expected-value mode, we associate aircraft with resources in the same way, but there we "know" that 10 percent of the C-17s will need nitrogen servicing, 15 percent will need oxygen servicing, and 10 percent will need repairs taking 60 minutes.

Table S.6 contains output from a Monte Carlo analysis of C-17 and C-5 aircraft needing fueling and cargo off-loading at the airfield. We asked for five aircraft of each type and specified that the C-17s had higher priority. For this analysis, we reduced the number and availability of ground-power units to show how such limited resources are reflected in capacity estimates, without making the run time unduly long. The entries in the table cover 100 iterations for the two-mission set.

The estimates show that aircraft servicing (and ground-power units in particular) is always the limiting resource, and that it always limits the number of C-5s that can be

[5]Table S.4 also illustrates several other points that we discuss in the text and appendices. The most important of these are (a) that resource-use times per aircraft (43 minutes for aircraft serviced on Ramp A and 52 minutes for aircraft serviced on Ramp B) are constant regardless of the number of resources at the airfield, but the aircraft time associated with the use of that resource (ranging from 49 minutes to 34 minutes for Ramp A and from 44 to 33 minutes for Ramp B) often is not; and (b) that ACE assumes that aircraft are serviced on the ramp having, first, the lowest aircraft ground time and, second, the greatest overall capacity. The latter rule results in some less-than-efficient servicing in the current version of ACE—in this example, for 18 and more k-loaders, the model assigns aircraft only to Ramp B, which then has the greatest overall capacity (because the parking constraint limits Ramp A), rather than first to Ramp A, which retains the shortest k-loader–use time, and then the overflow to Ramp B. We expect to correct this assignment for later releases of ACE.

Table S.5

C-17 Servicing Times (in minutes), by Aircraft Assigned a Particular Mission

Aircraft	Times Drawn for Servicing				Aircraft Ground
	Nitrogen	Oxygen	Repair	De-icing	Time
1	0	0	0	0	161
2	0	0	0	0	161
3	0	0	0	0	161
4	0	0	0	0	161
5	0	0	0	0	161
6	0	45	0	0	206
7	0	0	0	0	161
8	0	0	0	0	161
9	0	0	0	0	161
10	0	0	0	0	161
11	0	0	8	0	161
12	0	45	0	0	206
13	0	0	8	0	161
14	0	0	0	0	161
15	0	45	0	0	206
16	15	45	0	0	221
17	15	45	0	0	221
18	15	0	0	0	176
19	0	0	96	0	185
20	0	0	0	0	161
21	0	0	0	0	161
22	0	45	0	0	206
23	0	45	0	0	206
24	0	0	0	0	161
25	0	0	8	0	161
Average	1.80	12.60	4.80	0.00	176.77
Std Dev	4.97	20.62	19.18	0.00	22.57
Frequency					
Input:	0.10	0.15	0.10	0.00	
Output:	0.12	0.28	0.12	0.00	

SOURCE: Monte Carlo outputs of ACE.

NOTE: Estimates are based on each aircraft's requiring 150,000 pounds of jet fuel and the off-loading of 18 standard pallets, fueling via hydrants rated at 500 gallons per minute, and a quick-turn ground-servicing profile.

serviced, given the high-priority servicing of the C-17s. The entries in the lower portion of the table state that, given our assumptions, data, specifications, and values, the true expected value for the capacity of the airfield is 2.46 C-5s per day, given that 5 C-17s must also be serviced.[6]

[6]Running this same problem in expected-value mode produces an estimate of 5 C-17s and 2.80 C-5s in just under 2 minutes of run time on a 120-megahertz Power Macintosh, compared with the 141 minutes required by the 100 iterations of the Monte Carlo run. Microsoft Excel runs significantly faster, of course, on Microsoft Windows–based machines. The expected-value problem took less than 2 minutes, and the 100-iteration Monte Carlo problem, just over 70 minutes on a 133-megahertz Pentium. Times will differ on other computers.

Table S.6

Aircraft Throughput and Capacity Remaining, by Iteration

Iteration	Aircraft, by Mission No. 1	Aircraft, by Mission No. 2	Capacities Remaining After Final Mission: Parking	Servicing	Loading	Fueling	Other
1	5	2	26	0	24	46	9999
2	5	3	22	0	23	45	9999
3	5	3	25	0	23	45	9999
4	5	3	25	0	23	45	9999
5	5	2	26	0	24	46	9999
6	5	3	25	0	23	45	9999
7	5	2	26	0	24	46	9999
8	5	3	25	0	23	45	9999
9	5	3	25	0	23	45	9999
10	5	3	25	0	23	45	9999
11	5	3	25	0	23	45	9999
12	5	3	25	0	23	45	9999
13	5	3	23	0	24	46	9999
14	5	2	23	0	24	46	9999
15	5	2	26	0	24	46	9999
16	5	3	25	0	23	45	9999
17	5	2	26	0	24	46	9999
18	5	2	23	0	24	46	9999
19	5	2	23	0	24	46	9999
20	5	2	26	0	24	46	9999
•							•
•							•
•							•
91	5	2	20	0	24	46	9999
92	5	2	23	0	24	46	9999
93	5	2	22	0	24	46	9999
94	5	2	23	0	24	46	9999
95	5	3	22	0	23	45	9999
96	5	2	23	0	24	46	9999
97	5	2	26	0	24	46	9999
98	5	2	26	0	24	46	9999
99	5	3	25	0	23	45	9999
100	5	3	25	0	23	45	9999
Average	5.00	2.46	24.1	0.2	23.5	46.0	9999
Std Dev	0.00	0.49	1.69	0.19	0.40	0.48	0.00

SOURCE: Monte Carlo outputs of ACE.

NOTE: We requested 5 aircraft for each mission and set GPU inventory at 3, with the availability at 10 hrs per day for each. A "9999" indicates unlimited supply.

These estimates, along with other analyses documented in this report, illustrate several different findings. For example,

- Stopovers at destination (off-loading) airfields are much shorter than stopovers at on-loading points, because of the additional inspections, servicings, and repairs typically undertaken at the home or near-to-home airfield.
- For the C-17, the off-loading times for passengers, pallets, and small rolling stock are sufficiently short that they are covered (masked) by the times required for

routine inspection and servicing. Because of the masking, the number of buses available to transport passengers or the number of k-loaders available to transport pallets has almost no effect on the total ground time.

- On-loading times are not masked, because the aircraft typically are not loaded until the major inspections and servicings are completed; shortages of buses and k-loaders then cause small increases in ground times at on-loading points.
- People, pallets, and vehicles load easily and quickly; cargoes that are more difficult to handle can extend ground times by more than an hour.[7]

Recommendations

The variability in our estimates, along with the insights gained while conceiving and developing the model, led to our recommendations:

- First, because (a) so many factors potentially and commonly influence airfield capacity, (b) the influence of those resources on capacity is often decidedly nonlinear, and (c) ACE is now so easy and quick to use, we recommend that planners and others interested in airlift flow through airfields of various types and locations no longer use standard MOGs or standard ground times. Instead, they should estimate the specific aircraft ground time and airfield capacity for each stopover by carefully considering (a) the servicing, fueling, and loading operations needed for each type of mission stopping at each airfield and (b) the major ground resources available at each airfield.
- Second, we recommend that the mobility-modeling community now focus its research efforts on detailing realistic availability times for the commonly used pieces of material-handling equipment and on updating and validating its estimated distributions for aircraft repair times.

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[7]The times required for physically moving these cargoes into and out of the aircraft are usually long enough to cover the driving times of the transporters, so no more than two transporters are usually required. We have not modeled those transporters in this implementation of ACE.

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ACRONYMS AND ABBREVIATIONS

ACE	Airfield Capacity Estimator
AFM	Airlift Flow Module (same as MASS)
AGE	Aerospace Ground Equipment
AGS	Aircraft Generation Squadron
AMC	Air Mobility Command
BI	Block in
BO	Block out
CINCPACINST	Instruction [issued by] Commander in Chief of the Pacific
CONUS	Continental United States
DFSC	Defense Fuel Supply Center
DoD	Department of Defense
FPA	Fuel parking area
gpm	Gallons per minute
HMMWVs	Highly Mobile Multipurpose Wheeled Vehicles
HSV	Hydrant-service vehicle
IAP	International Airport
IOut	Iteration output: shows each iteration (of up to 6 missions) associated with a Monte Carlo analysis
LCOM	Logistics Composite Model
MASS	Mobility Analysis Support System (same as AFM)
MHE	Material-handling equipment
MOG	Maximum (aircraft) on ground
MRS	Mobility Requirements Study
NPC	Nonpalletized cargo
pax	Passengers

POL	Petroleum, oil, and lubricants
RIMS	Revised Intertheater Mobility Study
ROut	Run output: shown for each aircraft associated with 1 mission
SPR	Single-point (fueling) receptacle
TACC	Tanker-Airlift Control Center
TALCEs	Tanker-Airlift Control Elements
UTC	Unit-type code
WBELs	Wide-body elevator loaders

Chapter One

INTRODUCTION

BACKGROUND

Strategic airlift is an important component of the United States' ability to carry out its national policy. During Operation Desert Shield, the Air Force coordinated intensive flows of airlift from the United States and Europe into Saudi Arabian airfields, many of which had seldom, if ever, been visited by U.S. military aircraft. The Air Mobility Command (AMC) coordinates deployment, resupply, and relief flights to countries in Africa, Eastern Europe, and elsewhere on the globe on very short notice. Airfields in many of those countries are restricted in both size and resources, and AMC often has to deploy personnel and equipment to enroute, destination, and tanker airfields before useful flight schedules can be accommodated.

In many ways, airfields are as important to the United States' ability to project power or provide relief as are strategic aircraft. Airfield resources are used to prepare aircraft, aircrews, passengers, and cargoes for movement and to receive and recover them at destinations. To estimate the amounts of personnel, equipment, and supplies they can move into, out of, or through regions of economic, military, or political interest, Department of Defense planners need information on the capacities of airfields.

Estimates of airfield capacity figure prominently in both long-term force-structure studies and near-term operational planning. DoD long-range planners look for effective and efficient ways of responding to future crises. Planners shape programs to deliver military forces quickly and efficiently to distant locations. Therefore, planners need to know how different airfields will perform as aerial ports of embarkation, as enroute servicing points, and as overseas ports of debarkation. Investing heavily in troops, equipment, and transport aircraft can provide little in the way of projected forces if airfields and airfield resources are not there to support their projection.

Similarly, contingency planners responding to near-term needs around the world must be able to estimate quickly the ability of both familiar and unfamiliar airfields to support deployments, supply flights, relief efforts, evacuations, and other types of operations. Planners need to know (a) how much traffic an airfield can handle, given the resources available there at the moment, and (b) how much those resources would need to be augmented in order to handle more traffic.

Airfield capacity estimates are thus important inputs into any deployment and mobility analysis. AMC and the Office of the Secretary of Defense have recently accepted the Airlift Flow Module (AFM, formerly called the Mobility Analysis Support System, or MASS) as the preferred model for analyzing the airborne portion of deployments. AFM simulates the movements of airlifters as they transport passengers and cargoes along prescribed routes.

However, past runs of AFM have been criticized for being too optimistic—estimating that more cargo would be moved or that cargoes would be moved faster than they actually could be. Critics have called for improvements to two inputs of the model: the aircraft utilization rates, which specify the average flying hours per aircraft per day; and the maximum (aircraft) on ground, or MOG, values used to calculate airfield capacity. In response, AMC began to revise aircraft-utilization data while RAND undertook to improve the procedures by which airfield capacity is estimated.

PURPOSE

This research set two tasks for itself. The first task was to define *airfield capacity*. Previous definitions meant different things to different people, and, without a common definition, discussions often led to confusion. The second task was to demonstrate a methodology for computing the capacity of an airfield in a consistent and reproducible manner that would more accurately reflect the capability of the airfield's resources to process aircraft. For this second task, we constructed a mathematical model called the Airfield Capacity Estimator, or ACE.

AIRFIELD CAPACITY

We define *airfield capacity* as "the maximum number of missions that can be routed through and supported by a particular airfield during a 24-hour day, given specified airfield resources." *Missions* are essentially aircraft types that have been further categorized according to the aircraft *configuration* (for the maximum amount of cargo, for the maximum number of passengers, and for a mixed load of cargo and passengers), the type of layover (either quick-turn or full-service stop), and the service requirements and concurrency rules that govern servicing operations. *Airfield capacity*, then, does not refer to a specific number. Rather, it refers to a range of capabilities representing different combinations of missions that can be accommodated in a day. This range will change whenever mission demands and/or airfield resources change.

CONSTRUCTING THE MODEL

We visited several dozen airfields across the world, first, to gain a sense of how airfield personnel actually compute capacity and, second, to identify key activities to include in our model. We found that servicing, fueling, loading, and parking operations are frequently blamed for delays or slowdowns. This is not to say that, at a given airfield on a given day, some other activity might not be constraining; rather, these four functional areas were cited most frequently. Similarly, when selecting the

resources to model, we relied on information gathered from airfield personnel, both in the United States and overseas.

We make no attempt to model all airfield resources. Rather, we take the resources that appear to be most important, the most expensive, or the most visible in crisis situations, and we demonstrate how to combine detailed modeling of those resources with aggregate measures of the many other skills, supplies, and equipment needed in running an airfield and servicing modern airlift aircraft.

HOW THIS DOCUMENT IS ORGANIZED

The next chapter introduces our approach to modeling airfield capacity and explains how it improves on the current approach. Chapters Three, Four, and Five summarize our handling of the functional areas we regard as key: servicing, fueling, and loading, respectively. Chapter Six describes how to use ACE. Chapter Seven contains our conclusions and recommendations for further research. A number of appendices provide details on the procedures and methods: Appendix A presents the notation we use. Appendix B provides details of the ACE approach. Appendices C, D, and E present the key servicing, fueling, and loading equations. Appendix F describes the structure of ACE and details its use. Appendix G documents the ACE parameters and describes how to access them. Readers interested in understanding airfield capacity and gaining an overview of ACE should read the Summary, and Chapters One through Five, and Seven. Those interested in using ACE should read the entire report. Chapter Six and Appendix F constitute the "users' guide."

METHODOLOGY

The ACE approach to estimating airfield capacity builds on the methods traditionally used in defense studies; it formalizes and generalizes those methods; and it attempts to alleviate the major deficiencies found in earlier implementations. We begin with a short critique of capacity estimates used in recent airlift studies.

PREVIOUS METHODS FOR ESTIMATING AIRFIELD CAPACITY

Defense analysts have been providing estimates of airfield capacity for years. In support of actual operations, as well as in support of studies using models such as AFM, analysts have typically assembled three pieces of information about each airfield in question:

- that the resources (facilities, equipment, and supplies) at the airfield will be able to service *x* aircraft at a time
- that those resources will be available to work *y* hours per day
- that the average ground-service time for a particular type of aircraft will be *z* hours.

Analysts use those pieces of information to calculate that the airfield can service "*x* times *y* divided by *z*" aircraft per day.[1] For example, if the airfield can service three aircraft every 3 hours and 20 minutes, then, in a 20-hour day it can service (3 * 20/3.33 =) 18 aircraft.

Sometimes the capacity of a particular airfield is specified by single values for the three variables. This results in a single and unambiguous estimate of airfield capacity, as in "the airfield can support 10 aircraft per day." More often, however, several estimates of at least *x* and *y* are provided: one set for narrow-body aircraft and one set for wide-body aircraft; or, more recently, one set for each of several specific types of aircraft.[2]

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[1]See, for example, CINCPACINST 4600.0B, July 10, 1980.

[2]The value representing the number of aircraft that can be serviced, worked, or even simply parked at a particular airfield is often called the *maximum on ground*, or MOG, of the airfield. Usually the term "MOG" alone refers to parking; the term "working MOG" refers to servicing.

Even more recently, the capacity estimates have been broken down by type of airfield. In particular, ground-service-time estimates have differentiated between on-load, enroute, and off-load airfields. Table 2.1 shows the level of detail and the z values used in the Mobility Requirements Study–Bottom-Up Review Update (MRS BURU) of 1994 and 1995.

These standard times recognize that larger aircraft carry more cargo and passengers than smaller aircraft and thus take longer to on-load and off-load, that on-loading typically takes longer than off-loading, and that stopovers with no loading activities can be significantly shorter than stopovers with on-loading or off-loading.

Also, some analysts have begun to recognize the basic uncertainties and the multitude of problems associated with scheduling and servicing aircraft, and, as a final step in estimating airfield capacity, have reduced their estimates of capacity by 15 percent to allow for those uncertainties.

Even with this attention to airfield capacity, estimates of *airlift* capacity generated in 1993 and 1994, in association with analyses conducted by DoD and its contractors in support of C-17 acquisition decisions, were criticized as being overly optimistic, and the *airfield* capacity inputs were cited as one of the causes. Those criticisms led directly to this study.

Problems with the Previous Approach

Our initial investigations identified specific problems with the existing methods of estimating airfield capacity and with the manner in which those methods were used. We found

- a tendency to use optimistic service times
- a hesitancy to use detail—to consider the specific types and quantities of servicing resources that were or were not available for use at particular

Table 2.1

Planning-Factor Ground Times (hrs + mins)

	Airfield Designations			
			Off-Load	
Aircraft	On-Load	Enroute	Without Recovery Base	With Recovery Base
C-130	1 + 30	1 + 30	1 + 30	1 + 30
C-141	2 + 15	2 + 15	2 + 15	1 + 15
C-5	3 + 45	3 + 15	3 + 15	2 + 00
C-17	2 + 15	2 + 15	2 + 15	1 + 15
KC-10	5 + 00	1 + 30	3 + 00	3 + 00
KC-135	4 + 00	1 + 30	3 + 00	3 + 00

SOURCE: MRS BURU, 1994 and 1995.

airfields—partly because such information was sometimes not available, but more fundamentally because accepted and proper methods for analyzing and then consolidating resource or functional-area capacities into an aggregate airfield capacity did not exist.[3]

- a similar hesitancy to deal with complexity—to recognize that many airfields have more than one servicing ramp, more than one type of fueling system, and, perhaps most important, that most airfields in a typical day service more than one type of aircraft. Again, procedures for estimating airfield capacity under these conditions did not exist.
- a tendency to ignore major uncertainties.

These observations led us to conceive and then to construct a mathematical model called the Airfield Capacity Estimator.

OUR APPROACH

We improve on the traditional methods of estimating airfield capacity by first isolating and formalizing those methods and then generalizing them to include the many dimensions of capacity. In particular, our model recognizes

- up to 16 ground operations (sequenced into two ground-servicing profiles) to be performed on each aircraft
- more than 40 types of ground resources[4]
- up to 6 tasks in each operation for each resource
- up to 6 distinct areas for parking and servicing aircraft (each area may have a distinct hydrant-fueling system; all may be serviced by common fueling trucks and teams)
- up to 9 types of aircraft, with up to 6 of those intermingling operations in a typical day.

Figure 2.1, which is repeated in the Summary, depicts the layout for illustrative calculations throughout this report.

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[3]One of the most troublesome aspects of the previous approach was the manner in which analysts computed airfield capacity in the few instances when they considered more than one resource. This is the one place where we have seen Air Force planners actually do something "wrong." When they had estimates of MOG for several aspects of airfield capacity, they would all too often simply select the lowest of the MOG values and use that in their capacity equation. We show in Appendix B that the only proper method is to compute the capacity of each functional area, resource, or aspect and then choose the lowest-valued of those capacities.

[4]The current implementation of ACE recognizes over 40 separate ground resources. See Table 2.3 below.

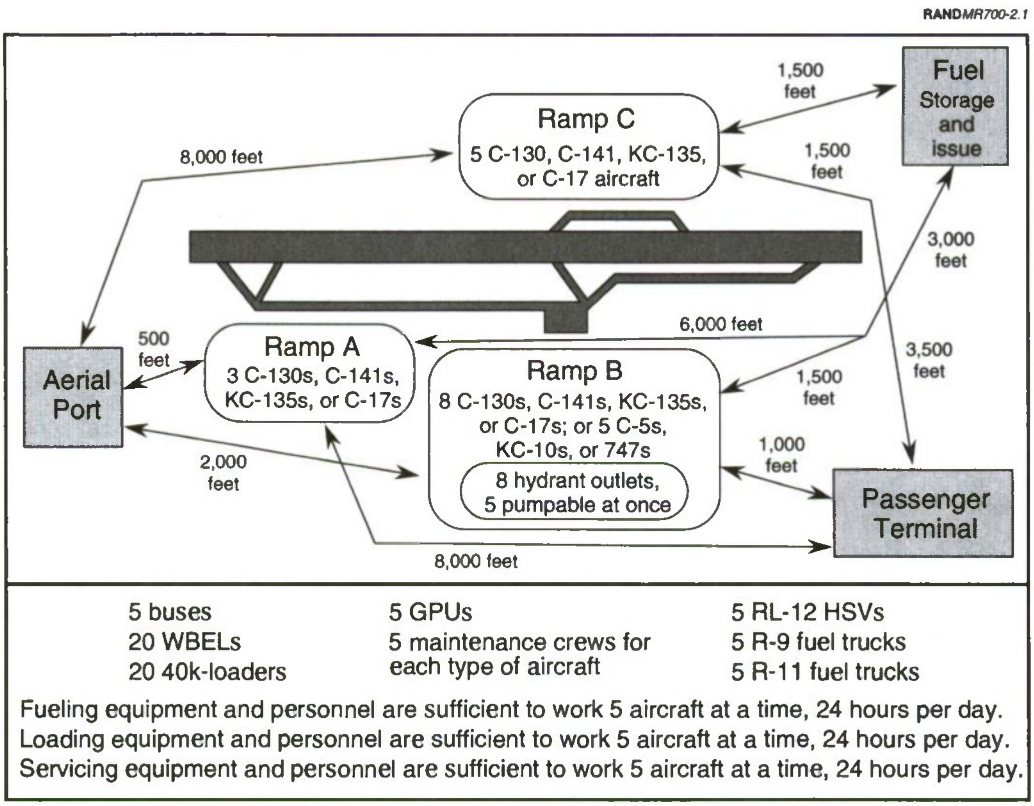

Figure 2.1—Airfield Layout for Illustrative Calculations

Formalizing the Methodology

Our model calculates how much time is required of each identified resource in servicing each aircraft assigned a particular type of mission. In our context, a *mission* or *mission type* specifies a particular type of aircraft and the specific ground operations—including the quantity of cargo to be on- or off-loaded and the quantity of fuel needed—that must be performed. A number of aircraft (per day) may be specified for each mission. In a single run, our model handles aircraft prioritized over as many as six missions. The model's outputs clearly identify the particular resource that limits the airfield's capacity for each given mission. If planners augment that resource, they will increase airfield capacity (until some other resource becomes the limiting factor); augmenting any other resource will not increase capacity.

For a single mission, we define the basic relationship between airfield resources and the airfield's capacity as

$$C = \text{Min}\left(\mathrm{R}_i * \mathrm{A}_i / S_i\right) \quad \text{over } i = 1,\ldots,\mathrm{n} \tag{2.1}$$

where C stands for the overall capacity of the resources at a particular airfield. Capacity is expressed as the number of aircraft assigned the particular mission that can

be serviced in one day. R_i represents the quantity of a particular resource *i* available at the airfield, A_i represents the hours per day that resource *i* is available to support airlift operations, and S_i stands for the time required of the resource *i* in servicing one aircraft.[5]

Then, for each modeled resource, we estimate detailed service-time equations—equations such as

$$S_i = \sum_j T_{ij} \quad \text{over } i = 1,\ldots,\text{n; and } j = 1,\ldots,\text{J} \tag{2.2}$$

that sum the times of individual tasks *j* performed with the resources *i*—and then use those service times in Eq. 2.1 to estimate airfield capacity for that mission.[6]

Generalizing the Methodology

Defense studies typically have used one or two resources in determining airfield capacity. Our approach goes much deeper. From visits to more than a dozen airfields and interviews with scores of service personnel and technicians, we have identified more than 40 types of resources (the *i*'s in Eq. 2.1) that contribute significantly to airfield capacity, and that can, when in short supply, constrain that capacity. We estimate specific use times and then specific capacities for each resource.

Aircraft Ground Time. Because our focus is the *capacity* of airfields—their ability to support airlift operations—and because aircraft are seldom moved during their ground stays, we associate each aircraft that comes into the airfield with a particular parking spot (or ramp space) and designate the time the aircraft must remain in that space as the *aircraft ground time.* Although any of the ground resources can constrain airfield capacity, the parking resource remains the first among equals in any airfield analysis, because it cannot easily be augmented and because it is directly associated with the aircraft.

Hence, we reserve special notation for *aircraft ground time*, defining it as

$$S_\text{p} = \sum_k G_k \quad \text{over } k = 1,\ldots,16 \tag{2.3}$$

with the p subscript representing parking and the G_k representing the ground operations listed in Table 2.2.

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[5]Roman letters identify *parameters*, which are specified outside the model and may retain a constant value over a number of runs. Italic letters identify *variables*, whose values are determined within the model during each run.

[6]As discussed below, some task times are fixed (parameters) and others are variables, which depend on mission and airfield specifications.

Table 2.2

Servicing Operations Determine Aircraft Ground Time

Full Service	Quick Turn
Block in	Block in
Post-flight inspection	Through-flight inspection
General servicing	General servicing
Nitrogen service	Nitrogen service
Oxygen service	Oxygen service
Repair	Repair
Pre-fuel	Pre-fuel
Transfer fuel	Transfer fuel
Post-fuel	Post-fuel
Off-/on-load passengers	Off-/on-load passengers
Off-/on-load cargo	Off-/on-load cargo
Pre-flight inspection	De-icing
De-icing	Block out
Block out	

As shown in the table, we model two ground-servicing profiles—a quick-turn profile and a full-service profile.[7] The *quick-turn profile* assumes aircraft are to be serviced and launched as quickly as possible. Under the *full-service profile*, longer and more-detailed servicing is performed and the aircraft may be required to remain on the ground for some specified amount of time. (The user inputs a minimum ground time to reflect, for example, that the aircraft cannot leave until its crew has rested.) Unless the *aircraft-servicing time* computed by ACE—the time required for servicing, fueling, and loading the aircraft—exceeds the minimum ground time, the *minimum ground time* is the default mission ground time for the full-service profile.

Use Times of Other Resources. In general, we model *resources* and the *tasks* those resources perform in completing the operations discussed above on the aircraft at the airfield. We consider specific operations, such as fueling and off-loading of cargo, to be composed of a series of tasks. And we relate specific resources and times to those tasks before aggregating the tasks into operations. For example, fueling may involve filling a tanker truck with fuel, driving it to an aircraft, hooking the fueling attachments to the aircraft, transferring fuel, unhooking, driving back to the fill stand, refilling the truck, etc. Each of those tasks may depend upon several resources.

Figure 2.2 depicts the overall operation of ACE. We capture in considerable detail the functional operations of aircraft servicing, fueling, and loading. For fueling and loading, we consider specific operations, such as hydrant fueling and off-loading cargo to be composed of a series of tasks. And we relate specific resources and times to those tasks before aggregating the tasks into the operations. For each of these areas, we identify the most-constraining resource and its limiting value of capacity. We then compare those capacities with more-aggregate capacities computed for air-

[7]As discussed in Chapter Three, we model two variations of the quick-turn profile, one allowing fuel to be transferred into the aircraft at the same time as servicing and loading operations occur, and one requiring the suspension of those operations while fuel is transferred.

RANDMR700-2.2

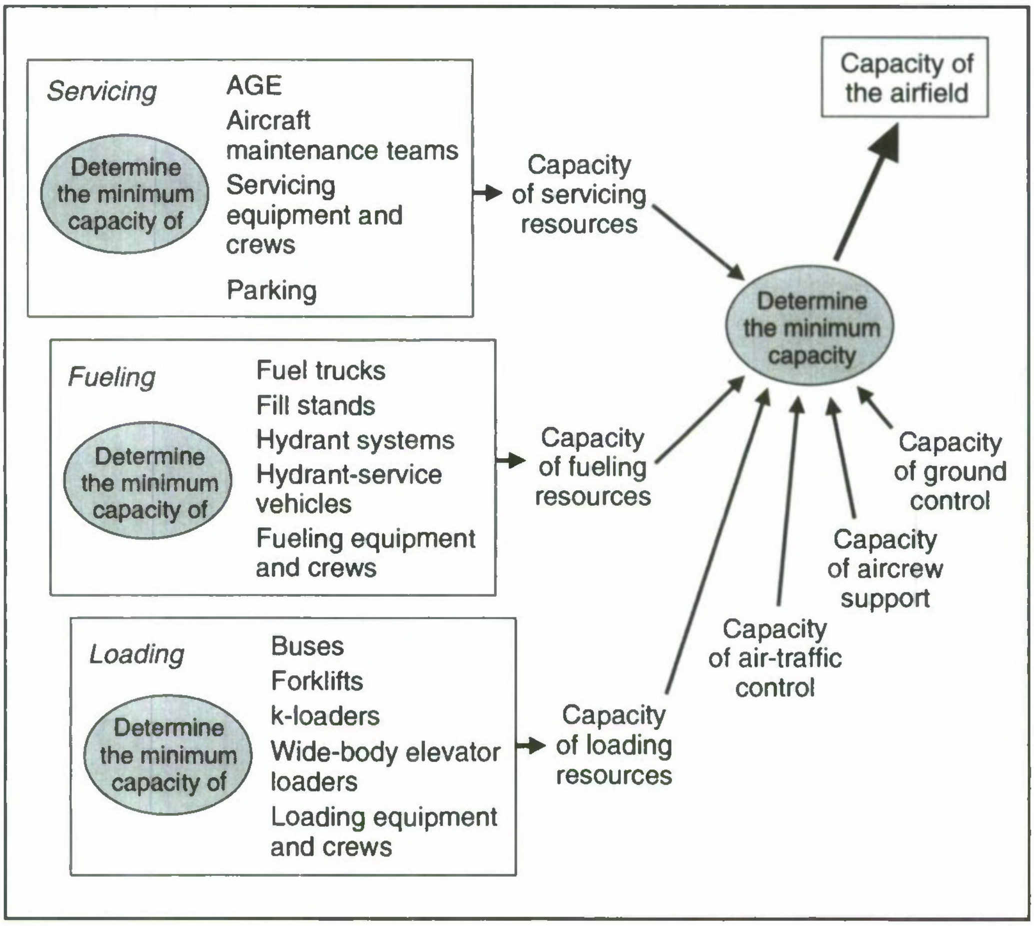


Figure 2.2—Structure of the ACE Model

traffic control, ground control, and aircrew services. Finally, we select the minimum capacity across all those functional areas to determine the airfield's capacity.

Table 2.3 lists the resources modeled in ACE.[8] In this table, the aggregate resource for each functional area—usually identified as "[area] equipment & personnel"—represents the packages of personnel, equipment, and supplies necessary for performing all of the flight-line, back-shop, and administrative activities associated with the functional area. For servicing, fueling, and loading, we include particular types of equipment. In designing ACE, we anticipated that users typically would employ a mix of aggregate and detailed data. Therefore, we singled out the tasks and the asso-

[8]The k-loaders transport pallets from the aircraft to the aerial-port storage and transfer area. WBELs lift pallets from the k-loaders to the access doors of the commercial, low-wing, high-body aircraft; they are not needed for military aircraft. Stairs provide the only egress route for the crews of commercial aircraft and must be attached to the aircraft when personnel are aboard; they are not a requirement for military aircraft. De-icers serve all aircraft, but calivars are needed only in de-icing the (high) tails of C-5s. Forklifts position pallets on k-loaders and trucks or move them around the aerial ports.

Table 2.3

Resources Modeled in ACE

Item	Item
Servicing	**Fueling**
Aerospace Ground Equipment	Hydrant systems
Ground-power units	Pumps
Gaseous-oxygen carts	Hydrants
Liquid-nitrogen carts	Hydrant-service vehicles
Liquid-nitrogen trucks	RL-12s
Liquid-oxygen carts	Commercial HSVs
Oil carts	Tanker trucks
Service stands	R-9s
Low-reach	R-11s
Medium-reach	Fill stands
High-reach	Fuel
De-ice trucks	Bulk storage
Calivars	Resupply
Passenger stairs	Intrafield transfer
C-130 service teams	Fueling equipment & personnel
C-141 service teams	
C-5 service teams	
C-17 service teams	**Loading**
KC-10 service teams	Material-handling equipment
KC-135 service teams	Forklifts
747 service teams	k-loaders
Cxx service teams	25k-loaders
Cyy service teams	40k-loaders
Parking space	60k-loaders
Servicing equipment & personnel	Wide-body elevator loaders
	Cochran
Aircrew Support	Wilson
Aircrew support equipment & personnel	TA-40
	60k-loader proxy
Air-Traffic Control	Loading equipment & personnel
ATC equipment & personnel	
Ground Control	
Ground control equipment & personnel	

ciated skills and equipment that we believed were most likely to be important, and focused on them individually, while handling other jobs and other functional areas more broadly. We discuss resources further in Appendix C.

IMPROVED ESTIMATES OF AIRCRAFT GROUND TIME

By recognizing multiple airfield resources, operations, and tasks, we can build up aircraft ground time and servicing times according to the particular needs of each mission. This provides both improved and more specialized estimates of airfield capacity.

Specifically, the current specification of ACE and the values associated with its basic parameters indicate that the standard ground times shown in Table 2.1 have been overly simplistic. For example, the standard ground time for a C-17 at an enroute

base, where it will be refueled but not on-loaded or off-loaded, was assumed to be 2 hours and 15 minutes in MRS BURU. Our estimates, presented in Table 2.4, show how the ground time of the aircraft increases as the quantity of fuel needed by the aircraft increases. One time does not work for all C-17s. And many aircraft—C-5s, KC-10s, and 747s in particular—hold and consume more fuel than the C-17 and, hence, may experience even more variability in fueling-related ground times.[9]

Similarly, our estimates in Table 2.5 of aerial port of debarkation (APOD) ground times with off-loads and on-loads and refueling—ranging from just under 3 hours to nearly 7 hours—suggest that Table 2.1's assumed time of 2 hours and 15 minutes for the C-17 underestimates the possible range of these aircraft ground times.[10]

The times in these tables preview our discussions in the next three chapters. The basic quick-turn servicing of a C-17 takes 1 hour and 30 minutes. Fueling increases that ground time, because servicing and loading activities are usually suspended while fuel is transferred into the aircraft. Loading, however, is typically conducted concurrently with servicing. In Table 2.5, the first three loading times are, in fact, masked by the servicing times. However, the final three (longer) loading times do increase the aircraft ground time substantially. We explore this complicated sequencing of ground operations, some of which can be performed concurrently and a few of which cannot, in Chapter Three.

IMPROVED ESTIMATES OF AIRFIELD CAPACITY

We have seen that different types of missions and different types of ground-servicing profiles imply different ground times for different aircraft at different airfields. But what do these different ground times imply for the capacity of those airfields to service aircraft? Do the different ground times make any difference?

Table 2.4

Fueling Significantly Affects C-17 Ground Times

Fuel Needed (1,000 lb)	Fuel-Transfer Time (hrs + min)	Aircraft Ground Time (hrs + min)
0	0	1 + 30
50	0 + 42	2 + 22
100	0 + 57	2 + 37
150	1 + 09	2 + 52

SOURCE: Expected-value estimates of ACE.

NOTE: Assumes quick-turn servicing profile, and resources as specified in Appendix G. The aircraft ground time of 2 hr + 50 min reported in Table S.3 is based on use of R-11s only.

[9]We assume the transfer occurs at 500 gallons per minute, or 50,000 lbs in 15 minutes. In Chapter Four, we examine how truck fueling influences aircraft ground times, and how having a limited number of trucks can influence the truck-fueling time.

[10]In Chapter Five we examine the ground times associated with on-loading and off-loading, and with shortages of material-handling equipment and loading crews.

Table 2.5

Off-Loading and On-Loading Significantly Affect C-17 Ground Times

Loading Operations	Loading Time (hrs + min)	Aircraft Ground Time (hrs + min)
Off-load 18 pallets	0 + 49	2 + 52
Off-load 18 pallets; on-load 18	1 + 00	2 + 52
Off-load 102 passengers	1 + 04	2 + 52
Off-load 102 passengers; on-load 102	1 + 53	3 + 36
Off-load oversized cargo	2 + 42	4 + 18
Off-load oversized; on-load oversized	5 + 12	6 + 48

SOURCE: Expected-value estimates provided by ACE.

NOTE: Estimates are based on quick-turn servicing of aircraft configured for maximum passenger or maximum cargo, and include transfer of 150,000 lb of fuel. Ground operations are conducted on Ramp B. Oversized cargo is represented by C-5 engines; being too large for the standard pallet, they require special handling, placement, and securing. We assume concurrency of loading and servicing, but fuel transfer must be isolated.

To answer these questions let us assume for the moment that the limiting resource at our airfield is parking, and that we are considering only one type of aircraft flying one type of mission. Then Eq. 2.1 says that the capacity of the airfield should be calculated as R, the parking places available, multiplied by A, the minutes per day they are available, divided by *S*, the time required of the parking places, which we assume here is equal to the ground time of the aircraft. Assume this airfield has 5 parking places available 24 hours per day.

Then, using the range of aircraft ground times in Table 2.5, we estimate that the airfield's capacity ranges from 17 aircraft per day for the longer stopovers to 41 aircraft per day for the shorter stopovers. This is a significant difference that planners and schedulers must keep in mind, and one that should not be obfuscated by the use of "standard" times for aircraft stopovers, regardless of the operations to be performed on the aircraft.

In cases where parking is not the constraining ground resource, the reductions in airfield capacity will depend on (and be inversely proportional to) the increases in use times for the constraining resources.

SERVICING

Because aircraft ground time is the heart of any estimate of airfield capacity, we model two ground-servicing profiles—a quick-turn profile and a full-service profile. Aircraft undergoing the quick-turn profile are serviced and launched as quickly as possible. Aircraft undergoing the full-service profile undergo longer and more-detailed servicing and may be required to remain on the ground for at least a certain specified length of time. Full-service stops usually occur at an aircraft's home base, or at least at a CONUS airfield.

Table 3.1 details the aircraft-servicing operations, and Table 3.2 defines those operations. Both ground-servicing profiles (full service and quick turn) include standard operations that are independent of the profile, as well as mission-related operations invoked by the user. Standard operations are of two types: those that occur for every flight, such as block in, servicing, and block out, and those that are probabilistic and occur for some but not all flights, such as the need for repair or for nitrogen or oxygen servicing. The quick-turn profile includes one through-flight inspection; the full-service profile has both pre- and post-flight inspections. These pre- and post-flight inspections probably involve more and longer repair actions, because aircrews are more inclined to submit write-ups for longer servicing stops, and repairers have more opportunity to address broken but not flight-critical items during extended servicing. Similarly, although the duration of the average oxygen service is generally independent of mission specification, the number of aircraft requiring this service typically increases for flights with extended ground time.

THE FULL-SERVICE PROFILE

The lower portion of Figure 3.1 illustrates the full-service profile.[1] It comprises 16 ground operations, several of which can be performed over two or three intervals. The five operations on the top line (block in, post-flight inspection, general servicing, pre-flight inspection, and block out) must be performed for every aircraft on every mission.[2]

[1]These servicing profiles and many of the servicing-operation times were established for us by Capt André Gerner during his Air Force Fellowship at RAND.

[2]Unless, as is explained in Appendix F, the user wishes to create a customized mission profile.

Table 3.1

Aircraft-Servicing Operations, by Service Profile and Requirement

Full Service	Quick Turn
Required and Constant, by Type of Aircraft, for Every Flight of Every Mission	
Block in	Block in
Post-flight inspection	Through-flight inspection
General servicing	General servicing
Pre-flight inspection	Block out
Block out	
Required on Specified Percentage of All Flights	
Repair	Repair
Oxygen servicing	Oxygen servicing
Nitrogen servicing	Nitrogen servicing
Optional, Specified in Mission Setup, for All Mission Flights	
Minimum ground time	
Optional, Specified in Mission Setup, on Specified Percentage of Mission Flights	
De-icing	De-icing
Optional and Time-Variable, Specified in Mission Setup, and Estimated Within ACE	
Fueling	Fueling
Passenger off-loading	Passenger off-loading
Passenger on-loading	Passenger on-loading
Pallet off-loading	Pallet off-loading
Pallet on-loading	Pallet on-loading
Nonpalletized cargo off-loading	Nonpalletized cargo off-loading
Nonpalletized cargo on-loading	Nonpalletized cargo on-loading

The other operations may need to be performed only on some missions or only or some aircraft (regardless of their assigned mission). The fueling and the loading operations are *mission-level specifications*: If aircraft on a particular mission are specified to receive 175,000 pounds of fuel each or to off-load 150 passengers each, then every aircraft assigned that mission will receive 175,000 pounds of fuel and off-load 150 passengers.

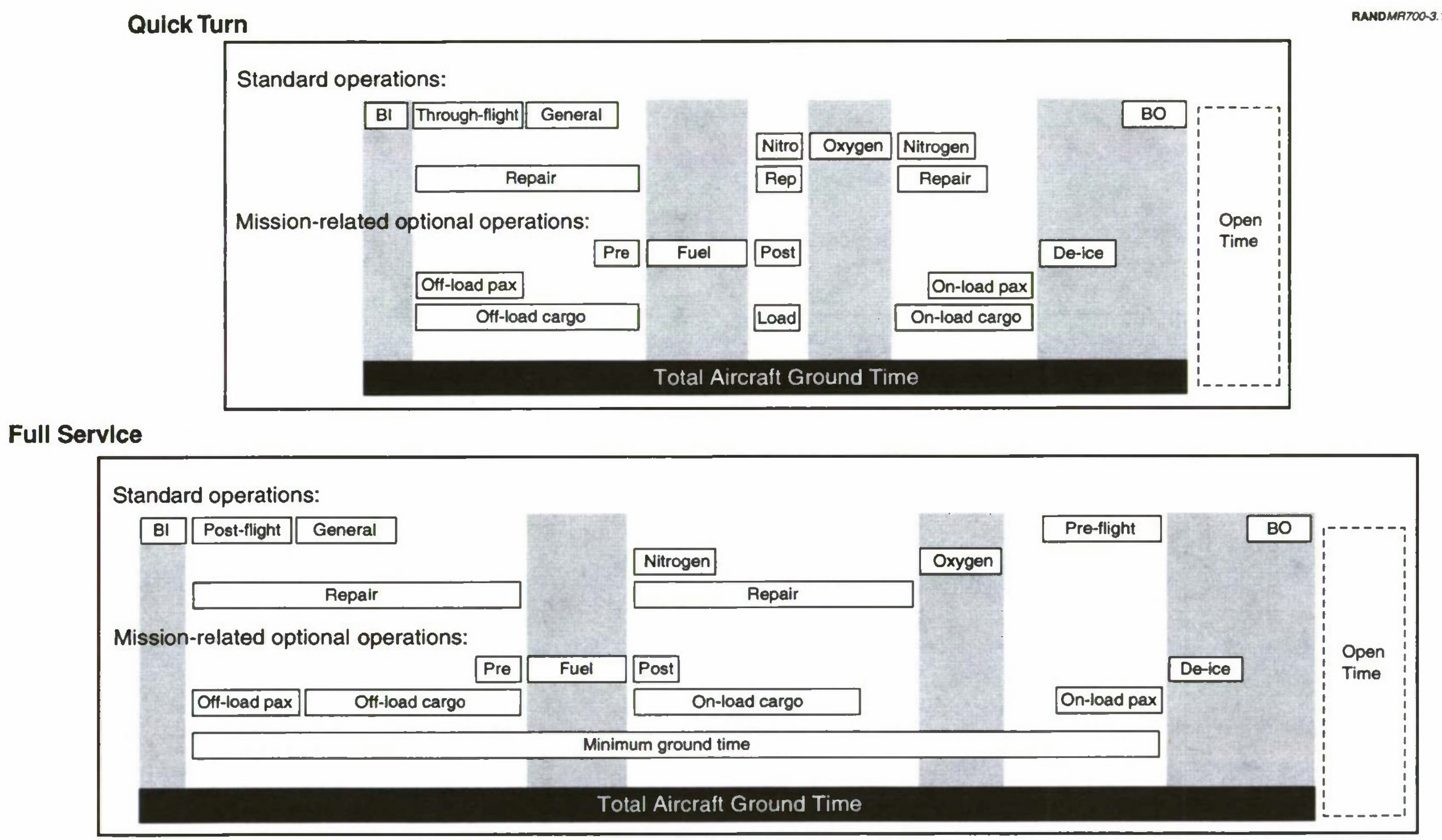
By contrast, the nitrogen-service, oxygen-service, and repair operations are *aircraft-level specifications*: Normally, each type of aircraft is assigned a particular probability of needing and receiving each of these services on each ground-servicing profile, independent of the mission it is on. We handle this variability in two ways: (a) We use expected-value calculations to estimate average resource-use times, aircraft ground times, and airfield capacities. This process does not yield the true "expected value" of capacity, because both the service-time equations and the capacity equations are nonlinear; but, in all the cases we have tested, it yields a close approximation to that value, and it is relatively quick. (b) We conduct Monte Carlo experiments, drawing values (for each aircraft in each mission) for those operational times from empirically derived distributions of past times. The draws for each set of missions can be

Table 3.2

Aircraft-Servicing Operations: Definitions

Operation	Definition
Block in	The period beginning when the aircraft is marshalled into parking and ending with engine shutdown.
Inspection	
Through-flight	Standard inspection given to aircraft on quick-turn layover. Performed shortly after engine shutdown.
Post-flight	Standard post-flight inspection given to aircraft on full-service layover. Performed shortly after engine shutdown but before the aircraft is secured.
Pre-flight	Standard pre-flight inspection given to aircraft on full-service layover. Performed before engine start.
Servicing	
General	All service actions performed by servicing personnel and not included in the following three operations.
Nitrogen	Servicing the aircraft with nitrogen; performed by servicing personnel.
Oxygen	Servicing the aircraft with oxygen; performed by servicing personnel.
De-icing	Removal of light snow and ice on the aircraft by servicing personnel.
Repair	Actions collectively representative of both preventative and restorative maintenance.
Fueling	
Pre-fuel	Actions required to prepare an aircraft for fueling.
Fuel transfer	Fuel-transfer period as determined by the fuel module.
Post-fuel	Actions required to secure the aircraft after fueling.
Loading	
Off-loading passengers	Servicing period associated with the physical transferring of passengers and their luggage from the aircraft and into buses or other vehicles.
Off-loading cargo	The unloading of palletized and nonpalletized cargoes from the aircraft.
On-loading cargo	The loading of palletized and nonpalletized cargoes into the aircraft.
On-loading passengers	The transfer of passengers and accompanying luggage from buses into the aircraft.
Block out	The period beginning with the initiation of engine start and ending when the aircraft is marshalled out of parking.

iterated 10, 100, or even more times, producing valid representations of the output distributions for use times, aircraft ground times, and airfield capacity. Given valid data, this method produces better estimates than the expected-value approximation, but it takes substantially longer. Details on both procedures can be found in Appendix C.



NOTE: In both ground-servicing profiles, operations drawn on the same level must occur sequentially; operations depicted in the same column may be done concurrently.

Figure 3.1—The Sequencing of Aircraft-Servicing Operations

Finally, the de-icing operation is both a mission and an expected-value specification. Its need, as a percentage of the aircraft on the mission, is specified explicitly by the user for each mission.[3]

We do not require the repair operation to be accomplished in a single application: It can be broken up for fuel transfer or for oxygen servicing, to keep the total ground time from becoming unnecessarily long. But recall that the full-service profile allows the aircraft to be kept on the ground for a specified amount of time. The user inputs a minimum ground time to reflect, for instance, that the aircraft is not moving while its crew is resting. Unless the mission ground time computed by ACE exceeds this value, the minimum ground time is the default mission ground time for the full-service profile.

THE QUICK-TURN PROFILE

Quick turns are less time-consuming than full-service stops; they are usually performed at enroute or off-loading airfields. We model two versions: one in which fuel transfer is isolated, as it always is in the full-service profile; and one in which ground time can be shortened even more by transferring fuel while certain other operations proceed.

As with full service, this profile allows any repairs that might be needed, general and nitrogen servicing, and the interruption of cargo off-loading and on-loading and repair for fuel transfer (when concurrency is not allowed) and for oxygen servicing (when it is needed). Our equations specifying the component times for these operations calculate the shortest-possible ground times.[4]

SCHEDULING OPERATIONS TO MINIMIZE GROUND TIME

The sequencing of aircraft ground operations depends on both resource and safety-related concerns. Table 3.3 details the conventions and protocols observed in structuring the profiles. Within that structure, however, we assume that schedulers attempt to minimize the ground time of the aircraft.

Because our goal is to estimate airfield capacity—i.e., the *maximum* number of aircraft that a particular airfield can support in a day, rather than some lower number that it can easily support—our procedures include two simple optimizations.

- First, when ground-servicing operations are interrupted for fuel transfer or oxygen servicing, we assume that the schedulers suspend all ongoing activities efficiently and at the same time. And after the isolated operations are completed, we assume that the schedulers resume all still-needed activities promptly.

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[3]De-icing is handled the same as nitrogen and oxygen servicing and repair when activated by the user. But for most examinations of most airfields, we expect it will not be activated.

[4]And, as noted above, if the user specifies that any of the operations are not to be performed for a specific mission, then the model sets the times for those operations to zero.

Table 3.3

Conventions Governing the Combinations of Aircraft-Servicing Operations

Convention Number	Description
1	Block in and block out are the first and last operations performed, respectively. No other operations take place at these times.
2	Due to the explosive potential of oxygen servicing and the hazardous environment surrounding de-icing, these operations occur in isolation from others, and from each other.
3	De-icing immediately precedes block out, since this operation is desired as close to takeoff as possible.
4	Pre-fuel precedes fuel transfer, which precedes post-fuel, with no other operations interposed. Owing to the inherent hazards of fueling and those resulting from an aircraft settling on its struts, off-/on-loads may occur concurrently with fuel transfer only when concurrent servicing is invoked by mission specification.
5	Although repair can occur anytime between block in and block out, it shall immediately follow block in by convention, because the majority of write-ups are normally identified by the aircrew prior to landing and are radioed ahead.
6	Through-flight or post-flight inspections immediately follow block in (concurrent with repair).
7	Off-loads always precede on-loads. Aerial-port off-/on-loads may occur concurrently with other servicing operations, except those operations previously identified as occurring in isolation (see Conventions 1 and 2), or fuel transfer, when concurrent servicing is not invoked by mission specification (see Convention 4).

- Second, when the airfield contains several areas where aircraft can be parked and serviced, we assume that the schedulers will assign aircraft to the *best* areas. That is, we assume that aircraft needing fuel will be parked at hydrants or near fill stands, that aircraft to be off-loaded will be parked near terminals, for example. The model accomplishes this optimal placement by looking at the ground time that would be associated with performing the specific operations required by each aircraft if it were parked in each different area, and then selecting the area associated with the shortest ground time. Finally, if it is necessary to service more aircraft flying that mission than can be accommodated in that (the best) parking area, then we assume that the next increment of aircraft is serviced in the area with the second-shortest servicing time, that the third increment is serviced in the area with the third-shortest servicing time, and so on.[5]

[5]These procedures are discussed further in Appendix B.

ESTIMATING SERVICE TIMES

Other than the aircraft ground time discussed in Chapter Two, times for aircraft-servicing resources are based on the times required for the tasks performed with those resources on mission aircraft. We accumulate the time each resource is needed for each ground operation in which the resource is used. Some resources—service stands, stairs—are used in several operations; others—oxygen carts, de-icers—are used only once. But in each case, we estimate the total minutes that the resource is needed in servicing one mission aircraft.

Parking time—the service time of the parking or ramp resource—is, as was noted on page 9, usually the same duration as aircraft ground time. The exception is when we add an "open time" increment to the parking time in order to allow for inefficiencies associated with the airlift authorities' scheduling of aircraft into the airfield.[6] Servicing times for ground-power units (GPUs) and aircraft-servicing crews are similarly easy to compute. A GPU powers the aircraft's electrical system for essentially the entire time it is parked at the ramp, and the servicing team is working at the aircraft for essentially that same time period. So one GPU and one servicing team are occupied with one mission aircraft for its total ground time.

The service times required of the other ground resources are computed individually. The capacity of each resource is computed by Eq. 2.1 by dividing the availability of the resource—the quantity available for use multiplied by the minutes it is available each day—by the computed service time per aircraft. The result is the total number of aircraft (associated with that particular mission) that can be serviced by each resource each day.

IMPROVED ESTIMATES OF AIRFIELD CAPACITY

We have seen that aircraft ground time depends significantly on the amount of fuel required and on the amount of cargo that must be handled. Table 3.4 shows that ground time also depends significantly on the ground-servicing profile.

Comparing the estimates shown in Table 3.4 for the several servicing profiles and types of operations for C-17s with the standard time of 2 hours and 15 minutes from Table 2.1 suggests, again, that the standard time is inadequate to capture the range of possible times. CONUS and home-base operations typically take 5 to 7 hours or longer. Enroute stops with fueling, and even off-loads with concurrent fueling, can take nearly 3 hours. And again, these differences in aircraft ground times reflect substantial differences in airfield capacities.

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[6]Open time should perhaps be modeled probabilistically, as is repair time. However, the parameters of its distribution must depend on the context, structure, and performance of the entire airlift system. The effects of changes in that system may, in fact, outweigh the randomness associated with any fixed system. In either case, such modeling is beyond our current capabilities.

Table 3.4

Profiles and Operations Affect Ground Time for C-17s

	Ground-Servicing Time (hours + minutes)		
		Quick Turn	
Item	Full Service	Sequential	Concurrent
Servicing only	4 + 45	1 + 30	1 + 30
Plus: 50k fuel	5 + 37	2 + 22	2 + 22
Plus: 100k fuel	5 + 52	2 + 37	2 + 37
Plus: 150k fuel	6 + 05	2 + 52	2+ 52
Plus: 150k fuel; 18 pallets off, on	6 + 32	2 + 52	2 + 52
Plus: 150k fuel; 102 pax off, on	6 + 56	3 + 36	3 + 21
Plus: 150k fuel; large oversized off, on	8 + 42	6 + 48	6 + 06

SOURCE: Expected-value estimates of ACE.

NOTE: Based on resources as specified in Appendix G. *Sequential* refers to the nonallowability, and *Concurrent* refers to the allowability, of loading and repair operations occurring while fuel is being transferred.

Thus far, the ground-servicing times we have estimated have not been affected by resource shortages: When fewer resources are available, fewer aircraft can be serviced, but the servicing time of those aircraft is not increased. In the next two chapters, we address resources whose reduced availability can and often does increase servicing time.

FUELING

In Chapter Three we discussed ground operations that require a fixed amount of time. For example, the general servicing for a C-17 on a quick-turn stopover takes 20 minutes at any airfield. In this and the following chapter, we examine operations—fueling and loading—whose times depend on the type and quantity of resources available at the particular base under investigation. For these operations, an increase in the number of resources available for use at an airfield has a twofold effect on airfield capacity. First, increased resources directly increase the working capacity of that resource. Second, and sometimes nearly as important, increased resources may decrease the amount of time each aircraft must spend on the ground at that airfield.

ACE models two common fueling methods: hydrant systems and trucks. The major tasks involved in each type of operation are listed in Table 4.1. These tasks take time and resources, both of which we track. The first resource to be exhausted becomes the constraining factor for that particular fueling method.

HYDRANT SYSTEMS

Many types (and many variations on those types) of hydrant-fueling systems can be found around the world. Each, however, consists of some combination of fuel storage, a number of fuel hydrants located near aircraft-parking spots, and a number of pumps for moving fuel from the containers to the hydrants and subsequently into the aircraft. ACE considers two essential pieces of information about each hydrant system: the number of aircraft it can service (pump fuel into) at once, and the rate at which it can pump that fuel into those aircraft.[1]

Hydrant-service vehicles (HSVs) interface between the hydrants and the aircraft. We model commercial as well as military HSVs, differentiating only by fuel-transfer rates:

[1]The two most-prevalent types of hydrant systems for strategic airlifters are the type II, or Pritchard, system, and the type III system. A typical Pritchard system can service a maximum of three aircraft simultaneously, at a maximum transfer rate of 600 gallons per minute (gpm) per aircraft. The type III hydrant system is bigger and faster, typically capable of pumping 2,400 gpm into a hydrant loop, which then feeds a number of individual fueling points. However, whatever the size of the system, the pressure will typically not be lowered to less than 500 or 600 gpm. That is, a 2,400-gpm system will often service 4 aircraft simultaneously, pumping fuel into each at about 100 gpm, but will seldom attempt to service, say, 5 or more aircraft (at 480 gpm or less). Many aircraft have minimum pressure (as well as maximum pressure) cutoffs.

Table 4.1

Tasks Associated with Fueling Aircraft

Fueling from Hydrants	Fueling from Trucks
	Fill truck(s) with fuel
Fueling Aircraft No. 1	**Fueling Aircraft No. 1**
Drive HSV to aircraft	Drive truck(s) to aircraft
Set up for fueling	Position and set up first (pair of) truck(s)
Transfer fuel	Transfer fuel
Secure aircraft after fueling	Remove first (pair of) truck(s)
Fueling Aircraft No. 2	Drive first (pair of) truck(s) to fill stand
Drive HSV to aircraft	Fill first (pair of) truck(s)
Etc.	Position and set up second (pair of) truck(s)
	Transfer fuel
	Remove second (pair of) truck(s)
	Drive second (pair of) truck(s) to fill stand
	Fill second (pair of) truck(s)
	Position and set up third (pair of) truck(s)
	Etc.
	Fueling Aircraft No. 2
	Drive truck(s) to aircraft
	Etc.

military HSVs handle a fuel flow of up to 1,200 gpm (gallons per minute); commercial vehicles usually handle 750 gpm.

TRUCK SYSTEMS

When hydrants are being used, the fuel flow proceeds without interruption. Fuel trucks, however, involve much stopping and starting. Trucks have much smaller fuel capacities than does the storage tank servicing the hydrants. When one truck has transferred its load, it must move away from the aircraft to make room for the next full truck. If too few trucks are available, these brief interruptions can turn into long delays while the trucks cycle back to the fill-stand area to replenish their tanks. Obviously, the longer the drive from the aircraft to the fill stand, the longer the fueling time.

Delays and Multiport Fueling

We model delays caused by an insufficient number of fuel trucks. (The logic for evaluating delays is similar in loading operations, for which pallet-carrying vehicles and buses may be in short supply.)

If we have only one fuel truck and the aircraft requires more than one truckload of fuel, we will always have some delay in the fueling of the aircraft. With only one truck, the delay will be equal to the *cycle time of the truck*—the time it takes to drive the truck from the aircraft to the fill stand, refill it with fuel, and return it to the aircraft—multiplied by the number of times the truck must recycle. On the other hand, there will be no delay if sufficient trucks are available so that at least one truck can

recycle in the time it takes the other trucks to hook up to the aircraft, pump fuel into it, and then unhook.

Another noteworthy aspect of truck fueling is that multiple trucks can transfer fuel into some aircraft simultaneously. The maximum number of simultaneous hookups is theoretically dictated by the number of single-point receptacles (SPRs) on the aircraft, but standard practice at most airfields allows no more than two trucks to be pumping into one aircraft at a time.

Multiport fueling requires fueling the aircraft in simultaneous "waves." Because all machinery near the aircraft must have engines off while fuel is being transferred, one truck cannot be hooking up or unhooking while the other is transferring fuel. In counterpoint to this activity, trucks arrive back at the fill stands in waves.

The fueling time for an aircraft thus depends on the amount of fuel required by the aircraft, the number of SPRs usable at one time, the maximum receive rate of the aircraft, the pumping rate of the trucks, the cycle time, the hookup-pump-unhook time, the number of trucks at the airfield, the number of trucks the fill stand can refill at one time, and the minutes per day the trucks are assumed to be available. Figures 4.1 and 4.2 illustrate how our fueling-time estimates can vary with the number of trucks and ports in use.

Figure 4.1 shows the substantial differences in fueling time for different amounts of fuel and different numbers of available fuel trucks. With the parameter values used in this illustration, fueling one KC-10 with 350,000 pounds of fuel using only 1 truck takes about 8 hours. About 4 hours of that time is spent hooking the truck up to the aircraft, transferring fuel, and unhooking the truck. And the aircraft spends about 4 hours waiting as the truck drives to the fill stand, refills with fuel, and returns to the aircraft. Adding more trucks reduces the waiting time. The second truck reduces that time to zero when the aircraft needs only 50,000 pounds (or less than 2 truckloads) of fuel, and the sixth truck reduces it to zero for even the most-demanding case (when 7 truckloads are required). Two of the KC-10's fueling ports (or SPRs) are used in the computations for Figure 4.1. Figure 4.2 concludes the example by showing the extra time required when only one of those ports is used.

IMPROVED ESTIMATES OF AIRFIELD CAPACITY

Table 4.2 shows our estimated effects of distance and truck availability on C-17 servicing times. For hydrant fueling, aircraft are assumed to park directly at the hydrants, so distance plays no part in their servicing. And because only one HSV is required or allowed per aircraft, the number of HSVs available at the airfield does not affect the fueling time.

For truck fueling, however, both distance (to the fill stand) and truck availability affect the fueling time. But the effects can be (made) small at most airfields. If four or more fuel trucks are available, the recycle time of each pair of trucks is more than

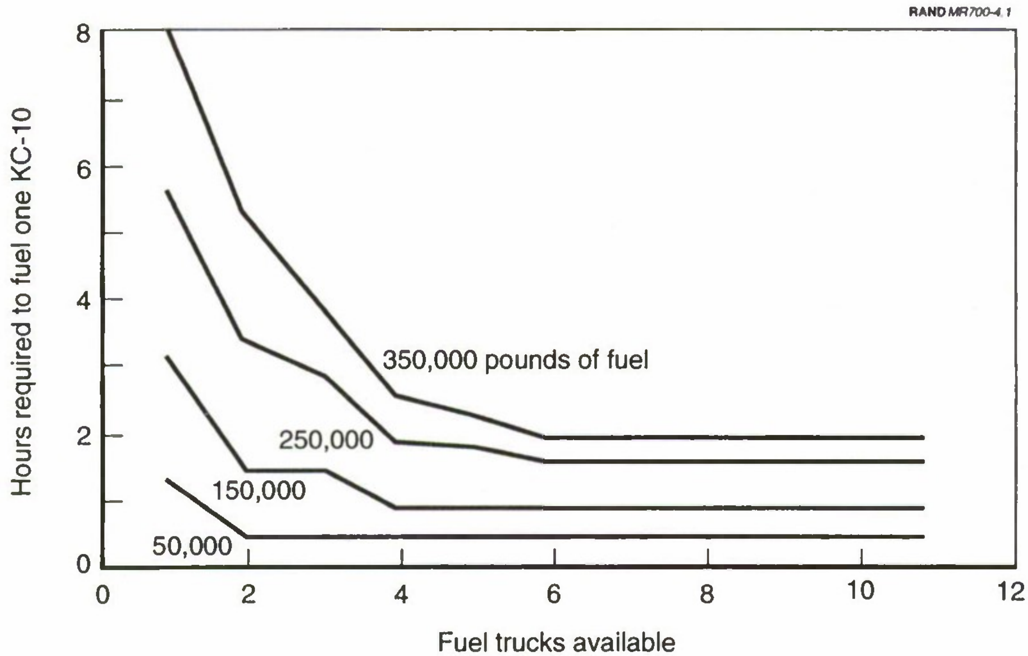

Figure 4.1—Fueling Time Decreases As the Number of Trucks Increases

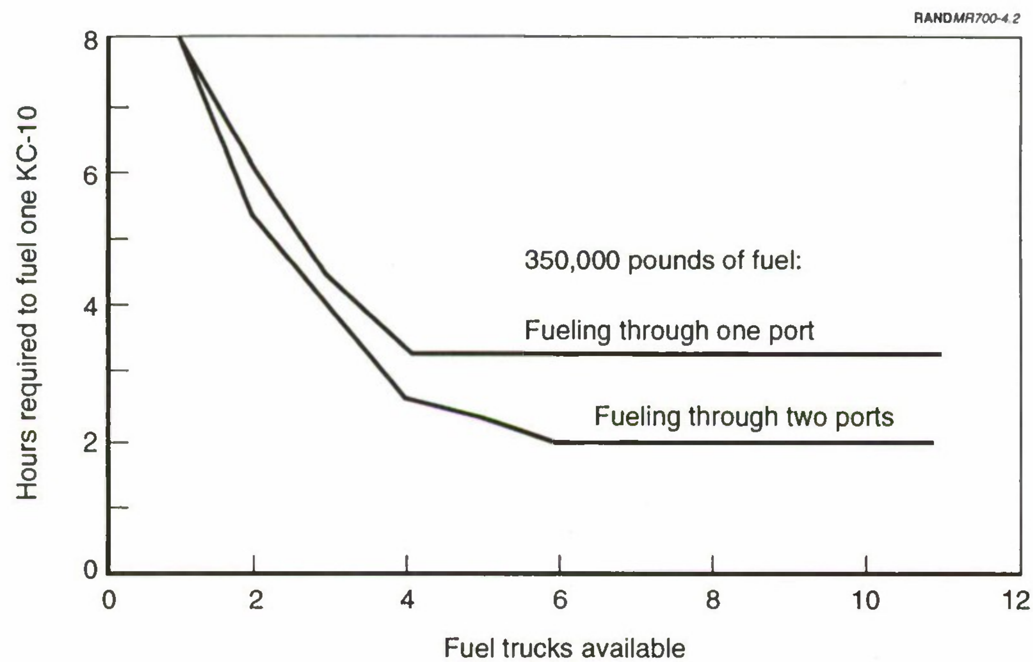

Figure 4.2—Additional Ports Also Decrease Fueling Time

Table 4.2

C-17 Ground Times, by Fueling Type, by Distance from Fill Stand, and by Number of Trucks Available (hours + minutes)

Hydrant Fueling	Trucks at the Airfield	Truck Fueling, by Miles from Fill Stands 0.25	0.50	1.00	2.00	3.00
2 + 52	1	4 + 13	4 + 34	5 + 16	6 + 40	8 + 04
2 + 52	2	3 + 13	3 + 22	5 + 40	5 + 16	5 + 52
2 + 52	3	3 + 07	3 + 16	3 + 34	4 + 10	4 + 46
2 + 52	4 or more	2 + 49	2 + 52	2 + 58	3 + 10	3 + 22

SOURCE: Expected-value computations of ACE.

NOTE: Hydrant-fueling estimates based on fuel transfer of 500 gallons per minute. All estimates assume 150,000 lb of fuel required per aircraft, quick-turn ground-servicing profiles, and no on-loading or off-loading of passengers or cargo.

covered by the on-aircraft time of the other pair, even with a round-trip distance of 3 miles. Fewer trucks (and, as we see in the next chapter, fewer pallet transporters and personnel buses) increase aircraft ground times, and increase them more than proportionately when driving distances are greater.

Fueling times, obviously, also differ greatly by type of aircraft. Table 4.3 shows the fuel capacity and the ground time associated with "filling it up" for the major airlift aircraft.

FUEL, PUMPING, AND RESUPPLY

We have discussed resources in terms of equipment and personnel; another vital resource for this operation is the fuel itself. Adding up the respective capacities of the hydrant-system pump houses and the fill stands does not begin to approximate the amount of fuel available at an airfield. Most fuel resides in bulk storage. In our capacity calculations, we consider the constraint on the number of aircraft that can be fueled in a day imposed by the total amount of fuel available at the airfield. And we

Table 4.3

Ground Times (in hrs + min), by Aircraft Type and Fueling Type

Aircraft	Fuel Capacity (lb)	Aircraft Ground Time: Fueling via Hydrants	Aircraft Ground Time: Fueling via Trucks	Ports	Number of Truckloads Required
C-130	62,000	1 + 41	2 + 09	1	2
C-141	150,000	2 + 50	3 + 02	2	4
C-5	332,000	4 + 24	4 + 36	2	9
C-17	182,000	2 + 52	2 + 56	2	5
KC-10	356,000	4 + 46	4 + 58	2	10
KC-135	203,000	5 + 11	5 + 51	1	6
747	370,000	4 + 00	4 + 12	2	10

SOURCE: Expected-value estimates of ACE.

NOTE: All fueling and servicing are conducted on Ramp B as shown in Figure 2.1. Aircraft ground times depend on times required for all servicing operations, not just fueling.

consider the constraints imposed by the external transport (resupply) and the internal (intra-airfield) transport of that fuel.

COMPOSITING VEHICLES

When we modeled fuel trucks, pallet transporters, WBELs, and passenger buses, we quickly learned that many varieties of each existed, each variety having differing capacities, speeds, and reliabilities. And we quickly learned that we could not expect to anticipate or prespecify the types that might be in inventory at any particular airfield. Hence, our approach is to specify the several most-prevalent types of military vehicles in each category, to specify one or two civilian types, if any, and then to allow the user to input information on any other types available at the particular airfield under investigation.

After the user has indicated how many of each vehicle category to consider, the model run begins by characterizing a customized, aggregate, composite vehicle that represents a weighted average of the various individual vehicles for each category. For example, if an airfield has one R-9 fuel truck that carries 4,600 gallons of fuel and one R-11 that carries 5,800 gallons, with the R-9 available on average 20 hours a day and the R-11 available on average 22 hours per day, we combine them into two composite trucks that carry an average of 5,229 gallons each and are available an average of 21 hours per day. Appendix B illustrates this derivation.

CHOOSING THE BEST FUELING SYSTEM

When an airfield has several parking areas for aircraft and/or several fueling systems available, we must consider how each affects the overall capacity of the airfield and the ground time of mission aircraft. We do this by having the user prioritize the missions under consideration. Then, for the first mission, if fueling is needed, the model estimates ground times for those aircraft parked in each of the areas and fueled by the systems available there. The model selects the area and system with the shortest ground time.

If that area and system of fueling cannot accommodate all of the aircraft on that mission, the model then selects the area and system with the next-shortest ground time. Each time a servicing area or a fueling system is selected for use by mission aircraft, that area or system is assigned to those aircraft and is no longer available for other aircraft or other missions. This process continues until either (a) all of the aircraft on the mission have been allocated space and resources for servicing or (b) the capacity of the airfield has been reached.

Chapter Five

LOADING

Loading operations involve passengers, cargoes, and aircraft. For on-loading aircraft, the operations include receiving and inventorying the cargo, operating the marshalling yard, checking the user's load plan, corralling passengers, transporting passengers and cargoes to the aircraft, loading and securing them, and then moving all equipment back to the terminal area.[1] Off-loading aircraft involves the same operations in nearly reverse order. For cargo and passenger operations, we model the flight-line and on-aircraft tasks, assuming that sufficient personnel and equipment will also be present to handle the "backroom" activities.[2]

Three complications arose in the modeling process. The first is that numerous transport vehicles are usually required for on-loading or off-loading the aircraft. Most aircraft that are used for military airlift can hold more than one busload of passengers or more than one k-loader[3] full of cargo. Several buses or other transporters need to be available in a timely manner or the aircraft will be kept waiting while the transporters cycle back to the aerial port. This means that we again need to account for delays.

A second complication is that cargo comes in many sizes and types. It seems, however, that with not much loss of realism we can limit our discussions to four types in addition to passengers: pallets, and small oversized, larger oversized, and outsized cargoes. Representative cargoes within these categories are 463L pallets (108 × 88 inches, loaded to a standard height of 96 inches), Highly Mobile Multipurpose Wheeled Vehicles (HMMWVs), C-5 engines, and helicopters, respectively. Neither the C-130 nor the C-141 can carry C-5 engines. The KC-135 and KC-10 aircraft can, in theory, carry small oversized cargo, but their narrow side doors make loading and unloading anything other than palletized cargo extremely difficult. Therefore, in

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[1] *On-loading* and *off-loadlng* refer, respectively, to moving cargo onto and off of aircraft or other transporters. We often use the term *loading* to refer to either or both activities.

[2] This assumption is perhaps most vulnerable for loading operations, because the receiving, inventorying and record-keeping, and packaging and palletizing operations can be quite important. Extended versions of ACE could model these activities as well.

[3] A *k-loader* is a large, self-propelled apparatus that can be raised and lowered hydraulically. It has rollers that enable rapid on-loading or off-loading of palletized cargo onto or from many types of aircraft and onto or from stationary loading docks.

practice, we dismiss that configuration.[4] Cargo-configured 747s can be loaded with oversized equipment if they have nose doors, but far more prevalent is the side-door configuration. The current version of ACE models this more-prevalent configuration, which, like the KC-135 and KC-10, is prohibitively labor-intensive to load with anything other than pallets. Table 5.1 summarizes RAND's assessment of the compatibility of aircraft and load types.

A third complication is that many aircraft carry "mixed" loads—i.e., some passengers, some pallets, and some oversized or outsized cargo. ACE counts number of passengers and pallets explicitly but considers only gross loading and handling times for other types of cargo. It allows up to three configurations per aircraft: Option A represents maximum cargo with incidental passengers; Option C represents maximum passengers with incidental cargo; and Option B represents a feasible intermediate configuration. Once users of ACE have chosen a configuration, they can analyze operations involving up to the maximum number of passengers and up to the maximum number of pallets (or their equivalent in nonpalletized cargo) associated with that option.

During contingencies, the majority of airlift cargo consists of passengers, pallets, and smaller oversized equipment, but the mix is often quite variable. The majority of cargo transported early in a deployment is *unit equipment*—typically consisting of about half passengers and half cargo, with the cargo being 75 to 80 percent rolling stock and 20 to 25 percent pallets. The major cargo transported later in the crisis is *sustainment cargo*—typically containing few passengers and with a cargo mix of about 75 to 80 percent pallets and 20 to 25 percent rolling stock. Our implementation of ACE addresses palletized cargo in greatest detail. We discuss that first, then passengers, and then other, nonpalletized cargo (NPC).

PALLETIZED CARGO

When considering load types, we focused the greatest amount of detail on palletized cargo, because we were interested in seeing the benefits of the new 60k-loader. This

Table 5.1

Compatibility of Aircraft and Load Types

Aircraft	Pallets	Small Oversized (HMMWVs)	Large Oversized (C-5 Engines)	Outsized (Helicopters)	Passengers (PAX)
C-130	Yes	Yes	No	No	Yes
C-141	Yes	Yes	No	No	Yes
C-17	Yes	Yes	Yes	Yes	Yes
C-5	Yes	Yes	Yes	Yes	Yes
KC-135	Yes	No	No	No	Yes
KC-10	Yes	No	No	No	Yes
747	Yes	No	No	No	Yes

[4] *Oversized cargo* exceeds the dimensions of a 463L pallet but is less than 1090 inches long, 117 inches wide, and 96 inches high. Air-transported cargo larger than this is called *outsized*.

vehicle not only transports more pallets than its predecessors, but also extends higher, so that commercial aircraft can be reached without additional (and notoriously fragile) wide-body elevator loaders.

Table 5.2 lists the pallet and passenger capacities of the major transport aircraft. Table 5.3 shows the capacities of major types of material-handling equipment. Military airlifters are built low to the ground, so wheeled vehicles can be driven on and off, and other cargo can be loaded using forklifts or k-loaders.

Commercial aircraft or their derivatives (such as the KC-135 and KC-10) cannot be reached by a forklift or by any but the 60k-loader. The 10k forklift, the 25k-loader, and the 40k-loader can deliver the cargo to the aircraft, but then one of the so-called wide-body elevator loaders, or WBELs, is needed to elevate the cargo to the level of the access doors.[5, 6]

Table 5.2

Cargo Characteristics of Aircraft Pallets and Passengers with Gear

	Configuration		
Aircraft	Maximum Pallets	Mixed	Maximum Passengers (Max-Pax)
C-130	6 / 0	4 / 23	0 / 91
C-141	13 / 0	12 / 9	0 / 160
C-5	36 / 73	36 / 73	0 / 343
C-17	18 / 0	9 / 51	0 / 102
KC-10	26 / 0	23 / 14	16 / 73
KC-135	7 / 0	6 / 14	0 / 65
747	42 / 10	42 / 10	0 / 400

SOURCE: Visits to Air Mobility Command and its airfields.

NOTE: C-5 seldom operates in max-pax configuration.

Table 5.3

Pallet Capacity of Material-Handling Equipment

Item	Pallets
Forklift	1
25k-loader	3
40k-loader	5
60k-loader	6
Wide-body elevator loaders (assorted)	2

SOURCE: Visits to Air Mobility Command and its airfields.

NOTE: Most buses are commercial, and sizes are not standardized.

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[5]WBELs include front-loading Wilsons and Cochrans and the side-/underbelly-loading TA-40. Because the 60k-loader functions as both a ground-cargo transporter and a WBEL, we include it when calculating the composite (aggregate) quantity of each class of equipment at the airfield.

[6]C-5 aircraft require especially high stairs for crew and passenger access, as do commercial derivatives. We model stairs in our aircraft-servicing model.

The differences in capacity between the aircraft and the ground vehicles are significant. For example, a C-5's full load of 36 pallets will fill six 60k-loaders, twelve 25k-loaders, or 36 forklifts. If we have sufficient vehicles waiting on the ramp when the aircraft parks, it can be loaded without delay. Or, as in the previous chapter, if some of the vehicles can drive to the cargo-storage area, have their pallets off-loaded, and then drive back to the aircraft before all the pallets have been removed from the aircraft, we can get along with fewer vehicles, still without incurring any delays. Calculating the relationship between the inventory of cargo-transporting vehicles at the airfield and the capacity of the airfield represents the main function of this portion of the ACE model.[7]

Table 5.4 lists the tasks that loading personnel must complete when off-loading and on-loading palletized cargo. The tasks are equivalent, but in somewhat different orders, for on-loading and off-loading. Times for some tasks differ, depending on the operation. For example, on-loading pallets onto a transporter at the terminal typically requires more transporter time than off-loading pallets there, because the on-loaded pallets must be secured before the transporter can move away.

PASSENGER OPERATIONS

We had not expected passenger buses to represent a potential constraint, believing that, if worse came to worst, passengers could always walk to or from the aircraft.

Table 5.4

Palletized Cargo–Associated Tasks Contributing to Resource-Use Times and Aircraft Ground Times

Off-Loading	On-Loading
Off-Loading Aircraft No. 1	**On-Loading Aircraft No. 1**
Position and set up WBEL	Position and set up WBEL
Drive transporter to aircraft	Drive transporter to aircraft
Transfer pallets from aircraft	Transfer pallets to aircraft
Drive transporter to terminal	Drive transporter to terminal
Unload pallets at terminal	Load pallets onto transporter
Drive transporter to aircraft	Drive transporter to aircraft
Repeat until aircraft is empty	Repeat until aircraft is full
Off-Loading Aircraft No. 2	**On-Loading Aircraft No. 2**
Deliver WBEL, etc., to aircraft	Deliver WBEL, etc., to aircraft
Etc.	Etc.

[7]On the other hand, some loading activities require little or no equipment and little time. A "combat off-load" consists of slowing the military airlifter on the runway or, preferably, on an apron, opening the rear door and removing the tie-down from the cargo, and then speeding the aircraft and allowing the cargo to roll freely through the rear door. However, we handle combat off-load as a mission type in our aircraft-servicing module, rather than as a use of loading resources.

Tactical operations involving airdrop require additional equipment and time. In these missions (which are not modeled in this version of ACE), all the aircraft in a formation depart and return at roughly the same time, demanding the same services. Furthermore, the loading operations take longer than usual when airdrop is involved, because the cargo (especially when packed in the container-delivery system) is difficult to handle and because paratroopers move more slowly because of their bulky gear.

Such a solution turned out to be unacceptable, however, because flight-line access is restricted. Even if it were not restricted, passengers walking across airfields with gear would inevitably slow down the operation. Passenger buses, therefore, are tracked. Table 5.5 lists the tasks we model for passengers and for nonpalletized cargo.

NONPALLETIZED CARGO

Our representation of NPC operations is even simpler. We assume that all nonpalletized cargo is wheeled, and that it can either be driven or pushed to and from the aircraft without additional equipment. Once at the aircraft, vehicles can be loaded in various ways: Driving is fastest (unless the user—who may be the only party with an appropriate operator's license—cannot be located), winching is safest, and using a k-loader with "toes" to transfer the vehicle may be considered a reasonable middle ground. We asked experts for estimates of on-loading and off-loading times of different nonpalletized cargo types, allowing them their choice of method. We use those times for full loads of NPC, and portions of those times for portions of loads. We do not model the preparation of NPC for airlift or its movement to the aircraft, but could add those activities in the future.

IMPROVED ESTIMATES OF AIRFIELD CAPACITY

We used different assumptions for the three *load configurations* introduced above. Estimates of aircraft ground time associated with Option A include time for cargo operations but assume that the (limited number of) passenger operations occur simul-

Table 5.5

Passenger and NPC-Associated Tasks Contributing to Resource-Use Times and Aircraft Ground Times

Passengers	Nonpalletized Cargo
Off-Loading	**Off-Loading**
Off-Loading Aircraft No. 1	Off-Loading Aircraft No. 1
Prepare aircraft	Prepare aircraft
Drive bus to aircraft	Unload cargo from aircraft
Off-load passengers into bus	Off-loading Aircraft No. 2
Deliver passengers to terminal	Etc.
Unload bus at terminal	
Repeat until aircraft is empty	
Off-Loading Aircraft No. 2	
Etc.	
On-Loading	**On-Loading**
On-Loading Aircraft No. 1	On-Loading Aircraft No. 1
(Prepare aircraft)	Prepare aircraft
Load pax on bus at terminal	Load cargo into aircraft
Deliver pax to aircraft	On-Loading Aircraft No. 2
Load pax into aircraft	Etc.
Return bus to terminal	
Repeat until aircraft is empty	
On-Loading Aircraft No. 2	
Etc.	

taneously and are completed within the cargo times. Estimates of aircraft ground time associated with Option C include time for passenger operations (and the handling of the passengers' personal gear) but assume that the (limited number of) cargo operations can be handled simultaneously and are completed within the passenger times. Estimates of aircraft ground time associated with Option B, which may involve a substantial amount of cargo and number of passengers, include times for sequential cargo and passenger operations.

For each mission to be analyzed, the user specifies the type of aircraft, its configuration, the split of space in the cargo bay between nonpalletized and palletized cargo, and the quantities of pallets, passengers, and nonpalletized cargo to be off-loaded and on-loaded at the airfield. We model three types of nonpalletized cargo, but we allow only one of these types to be handled per loading procedure (off-load/on-load) per mission.

Table 5.6 shows how our estimates of C-17 ground times for passenger, pallet, and NPC operations vary with distance and vehicle availability. We assume that NPC cargoes are driven or towed to the aircraft, and we do not model that transport. Hence, our estimates of ground time for aircraft on-loading or off-loading NPC do not depend on distance or vehicle availability. These estimates suggest that off-loading a full load of C-5 engines from a C-17 requires a ground time of just over 3 hours.

Off-loading passengers or pallets is faster. And recall that for these cargoes, we do model vehicles and vehicle availability. Our estimates of ground time for aircraft carrying personnel do differ by distance and by vehicle availability. But note that our estimates of ground time for C-17s carrying pallets do not differ by vehicle availability, because, even with delays associated with waiting for vehicles, the off-loading times are still masked by the times required for routine servicing.

Vehicle availability depends on the operating hours and the operating rules and procedures of the airfield, as well as on the reliability and maintainability of the vehicles. Table 5.7 shows how vehicle availability—in this case, the availability of k-loaders—affects off-loading times. Information we received from AMC concerning the "up"

Table 5.6

C-17 Ground Time (in hours + minutes), by Off-Load and by Distance (in miles) from Terminals

Vehicles at the Airfield	Passenger Operations, by Miles from Pax Terminal			Pallet Operations, by Miles from Cargo Terminal			NPC Ops
	0.25	0.50	1.00	0.25	0.50	1.00	
1	1 + 53	1 + 56	2 + 04	1 + 30	1 + 30	1 + 41	3 + 09
2	1 + 31	1 + 31	1 + 35	1 + 30	1 + 30	1 + 41	3 + 09
3	1 + 31	1 + 31	1 + 32	1 + 30	1 + 30	1 + 41	3 + 09
4 or more	1 + 31	1 + 31	1 + 32	1 + 30	1 + 30	1 + 41	3 + 09

SOURCE: Expected-value estimates of ACE.

NOTE: Missions require off-load of a complete load of either passengers (using buses), pallets (using 40k-loaders), or C-5 engines (using unspecified equipment). No on-loading or fueling occurs.

Table 5.7

C-5 Times (in minutes) and Capacities (in aircraft per day), by Number of k-Loaders Available, by Hours the k-Loaders Are Available per Day, and by Distance from Ramp to Pallet-Storage Area (0.25 or 1.00 mi)

Vehicles at	k-Loader Time		Aircraft Loading Time		Aircraft Ground Time		Airfield Capacity	
the Airfield	0.25 mi	1.00 mi	0.25 mi	1.00 mi	0.25 mi	1.00 mi	0.25 mi	1.00 mi
Vehicle availability of 2.35 hours per day								
1	96	144	113	158	151	180	1.5	1.0
5	96	144	113	158	151	180	7.3	4.9
10	96	144	113	158	151	180	14.7	9.8
15	96	144	83	110	142	150	22.0	14.7
20	96	144	71	92	142	142	29.4	19.6
25	96	144	64	79	142	142	36.7	24.5
30	96	144	64	74	142	142	43.9	29.4
35	96	144	64	69	142	142	43.9	34.3
40	96	144	64	67	142	142	43.9	39.2
45	96	144	64	67	142	142	43.9	43.9
50	96	144	64	67	142	142	43.9	43.9
Vehicle availability of 10 hours per day								
1	96	144	113	158	151	180	6.3	4.2
2	96	144	113	158	151	180	12.5	8.3
3	96	144	93	126	143	158	18.8	12.5
4	96	144	79	106	142	148	25.0	16.7
5	96	144	69	90	142	142	31.3	20.8
6	96	144	64	78	142	142	37.5	25.0
7	96	144	64	74	142	142	43.8	29.2
8	96	144	64	70	142	142	43.9	33.3
9	96	144	64	67	142	142	43.9	37.5
10	96	144	64	67	142	142	43.9	41.7
11	96	144	64	67	142	142	43.9	43.9
12	96	144	64	67	142	142	43.9	43.9

SOURCE: Expected-value computations of ACE.

NOTE: All estimates assume a full load of 36 pallets off-loaded during quick-turn ground servicing. No passenger operations, loading of cargo, or fueling is required. Each k-loader is assumed to be available as indicated. Other resources, except for distance to loading facilities, are as shown in Figure 2.1 and Appendix G. Ground-power units can support 43.9 C-5s per day.

time of k-loaders and WBELs shocked us. These pieces of equipment are apparently so old and so fragile that they spend more time being worked on than working. This table contains two sets of estimates: one for k-loaders with an average availability of 2.35 hours per day, the current airfield estimate, and one showing how ground times could be reduced and capacities increased if the k-loader availability could be increased to 10 hours per day.

The estimates shown in the top portion of the table indicate the large number of transporters needed to reduce the aircraft ground time to its minimum value—15 k-loaders when the distance from the aircraft-parking ramp to the pallet-storage area is 0.25 mile and 20 k-loaders when the distance is 1 mile. But even more important is the direct effect of the downtimes on loading and airfield capacity. Because it takes 144 minutes of k-loader time to off-load an aircraft parked on the 1-mile-distant

ramp, if each k-loader is really available only 141 minutes per day, then the capacity of each k-loader is less than one aircraft per day.

The estimates in the bottom portion of Table 5.7 show what the benefits of improved availability could be. Because availability appears in the numerator of the right-hand side of Eq. 2.1, any increase in availability results in a proportional increase in resource capacity. If it also decreases delay time, the increase can be augmented by a second-level effect. But, as we have seen, the reductions in times can be masked by the times required for other ground operations, and the increase in the capacity of one resource can be negated by shortages of other resources.

Engine-Running Off-Loads

We can imagine some situations for which such a premium has been placed on short ground times that aircraft-servicing personnel are instructed to bypass all ground operations except those absolutely necessary for a short off-loading stopover: block in, cargo off-load, and block out. In such circumstances, every minute saved in off-loading will result in getting the aircraft back in the air 1 minute faster. In the following chapter and in Appendix F, we describe how easily ACE can be customized to estimate aircraft ground times and airfield capacities associated with engine-running off-loads and other abbreviated stopovers.

COMPOSITING VEHICLES

As with fuel trucks, we found it practical to identify and describe the several most-prevalent types of military and commercial pallet transporters, WBELs, and passenger buses, and then allow the user to input information on any other types available at the particular airfield under investigation.

THE BEST PARKING FOR LOADING AND/OR FUELING

As discussed in Chapter Four, when an airfield has several parking areas for aircraft and/or several fueling systems available, we consider how each affects the overall capacity of the airfield. The user prioritizes the missions under consideration and then, for the first mission, the model estimates ground times for the aircraft if they were parked in each of the areas and serviced there, and selects the area with the shortest ground time. If that area cannot accommodate all of the aircraft on that mission, the model then selects the area with the next-shortest ground time. This process continues until either all aircraft for all missions are serviced or the limit of some resource is reached.

Chapter Six

USING ACE

Now that we have discussed factors constraining servicing, fueling, and loading operations, we turn to ACE as a whole.

Version 2 of ACE is written in Visual Basic for Applications (VBA) and runs on a PC or Macintosh with Microsoft Excel 5 or Excel 95 and a high-resolution monitor—hardware and software now available to most analysts. The model consists of four workbooks totaling about 2.7 megabytes of data, equations, instructions, and input and output screens.

Figure 6.1 shows the general structure of ACE. The model specifies aircraft-servicing, fueling, and loading operations in detail and air-traffic control, ground control, and aircrew support operations in aggregate. The model contains three types of parameters:

- global parameters, such as aircraft and vehicle capacities, which we assume remain constant over all missions and all airfields
- airfield parameters, such as the number of ramps, their capacity, availability, etc., which usually remain constant over a number of missions
- mission parameters, such as the quantity of fuel needed and the number of pallets to be on-loaded, which differ for each mission.

Software for the ACE model, described in this report, is available on the RAND homepage at http://www.rand.org/publications/MR/MR700/ACE/.

To use ACE,

1. Load the ACE.XLS workbook. This loads the other workbooks as well and presents the user with the "Welcome" screen. See Figure 6.2.
2. Accept or adjust the global parameters, such as vehicle capacities and speeds, fuel density, and the like.
3. Specify or confirm the airfield parameters, such as ramps, distances, resources, availability times, and the like. Import or export a complete airfield-parameter file.

RAND MR700-6.1

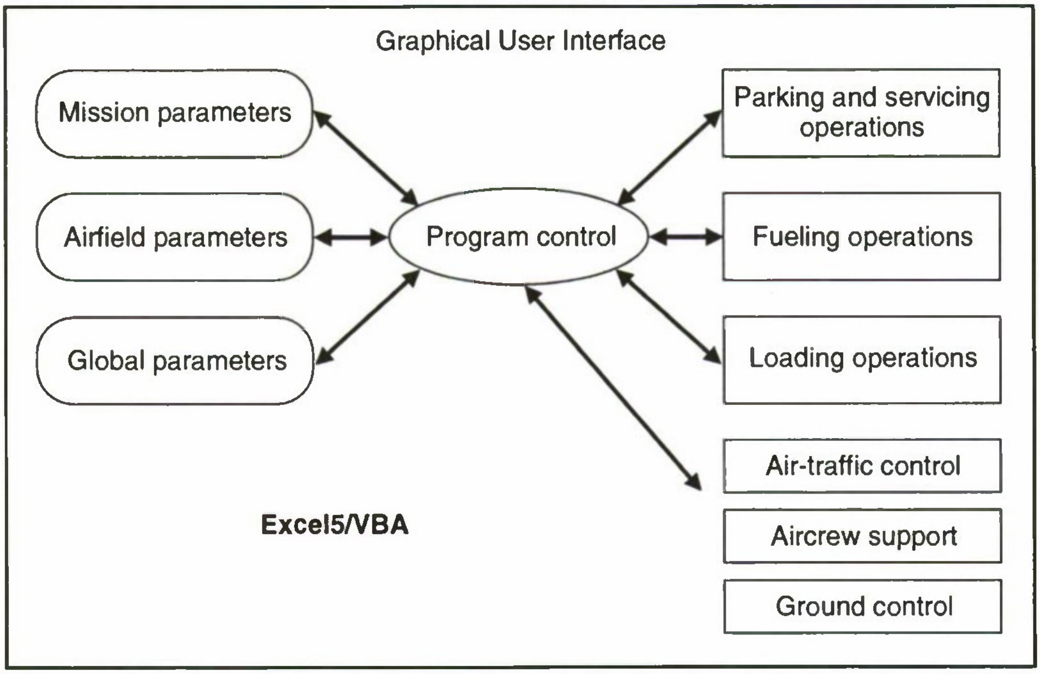

Figure 6.1—Structure of ACE

RAND MR700-6.2

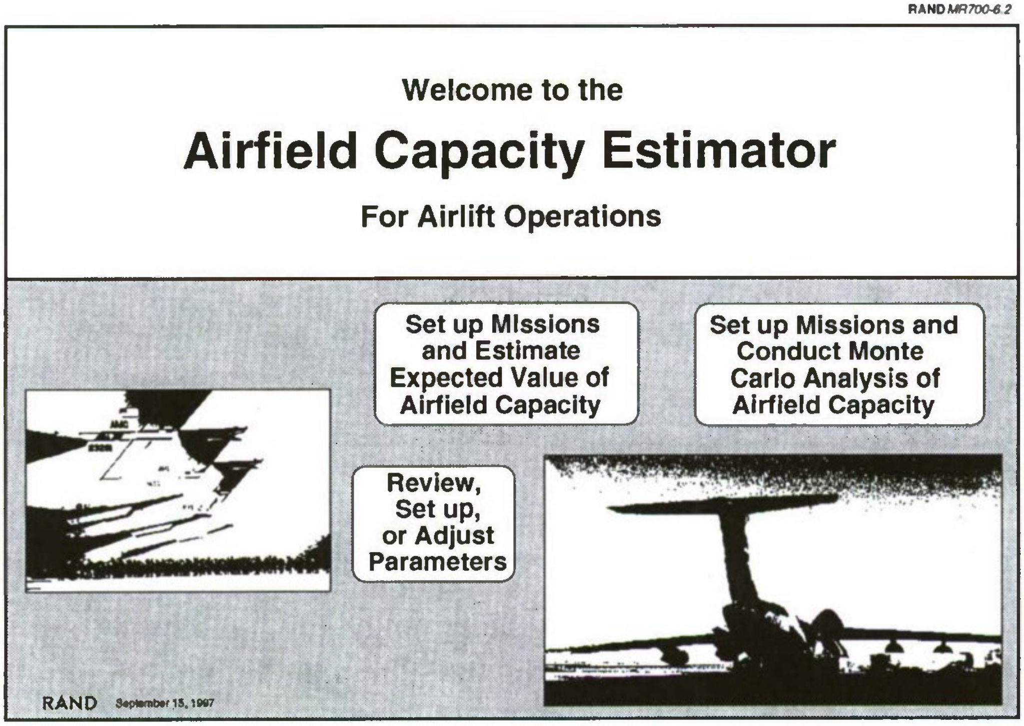

Figure 6.2—Initial Screen

4. Select the mode of analysis, either expected-value calculations or Monte Carlo estimation. For the Monte Carlo estimation, specify the number of iterations for which the mission set is to be evaluated.
5. Specify one or more missions, including aircraft type, configuration, number of aircraft, intensity and frequency of ground operations, servicing profile, and the like. Then click on one of the "evaluate" buttons.
6. Observe the estimates displayed on the output screen. And, if desired, review the several data-setup, computation, and tracking screens.

In this chapter, we summarize steps 3, 4, and 5. Details on these steps and descriptions of steps 2 and 3 are presented in Appendices F and G.

SPECIFYING AIRFIELD PARAMETERS

The initial ACE screen allows the user to branch to the ACE_DATA.XLS workbook to specify or confirm parameters or to select a mode of operation and immediately begin to set up missions. Choosing the parameter option causes the Parameter-Control screen to appear. See Figure 6.3.

RAND MR700-6.3

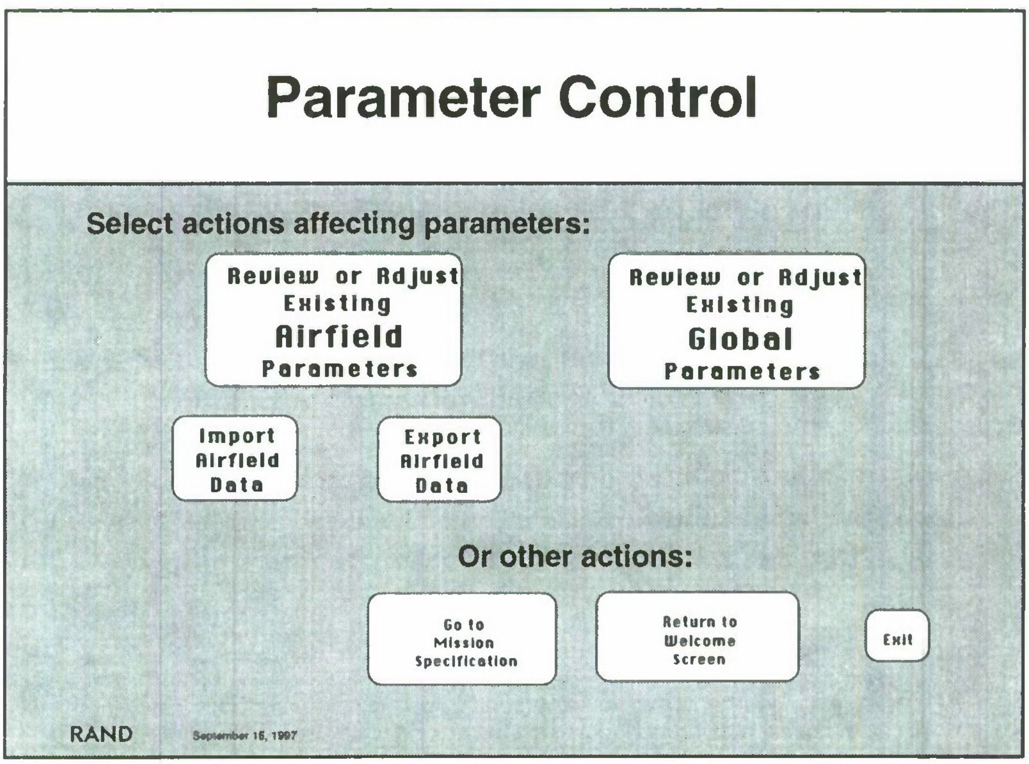

Figure 6.3—Parameter-Control Screen

Branching is accomplished by pressing what Excel calls "button objects" and what we refer to simply as *buttons*.[1] Pressing the "Review or Adjust Existing Airfield Parameters" button will cause the Airfield-Parameter Control screen to appear. This screen allows the user to branch to the several types of airfield parameters. The structure of the lower-level branches and the types of parameters they access is shown in Figure 6.4.

Examination of the individual screens will reveal just what parameters are contained where. Figure 6.5 shows, as one example, the Parking and Hydrant-Fueling Parameters screen. On this, and on all other Airfield-Parameter screens, the user is expected to enter specific airfield information. The preexisting entries or the examples shown in this report provide guidelines on the format, units, and locations for the entries.

When the airfield parameters are entered and verified, the user branches back to the "Welcome" screen of the ACE.XLS workbook and indicates whether to set up for expected-value calculations or for Monte Carlo estimations.

SELECTING THE MODE AND SPECIFYING THE ITERATIONS

When the user specifies Monte Carlo estimations, the program displays the Monte Carlo screen shown in Figure 6.6. This summarizes the computations that will follow and queries the user for the number of iterations the model is to evaluate. Control is then passed to the Mission screen, which is where the user goes directly after selecting the expected-value alternative. This screen is shown in Figure 6.7.

SETTING UP THE MISSIONS

The planner works from top to bottom and from left to right in setting up missions. ACE allows up to six missions to be set up and evaluated at once.

The Upper Menus

Mission ID. In setting up a mission, the planner first has the option of entering a new identification symbol or name for the mission. This is the only data field on the Mission screen that accepts keyboard characters, and any characters are allowed.

The remainder of the mission parameters are specified via buttons and "dropdown" objects. When clicked, buttons initiate an assigned macro or subroutine. Dropdowns contain menus from which the user can select one item.[2]

[1]A *button object* initiates the operation of an assigned macro or subroutine.

[2]The user selects an item from the list in the dropdown by clicking the down arrow on the right side of the dropdown. Clicking the arrow causes the list of items to appear below the dropdown. The user can then select one item from the list. After the selection is made, the list disappears and the dropdown displays the selected item.

RANDMR700-6.4

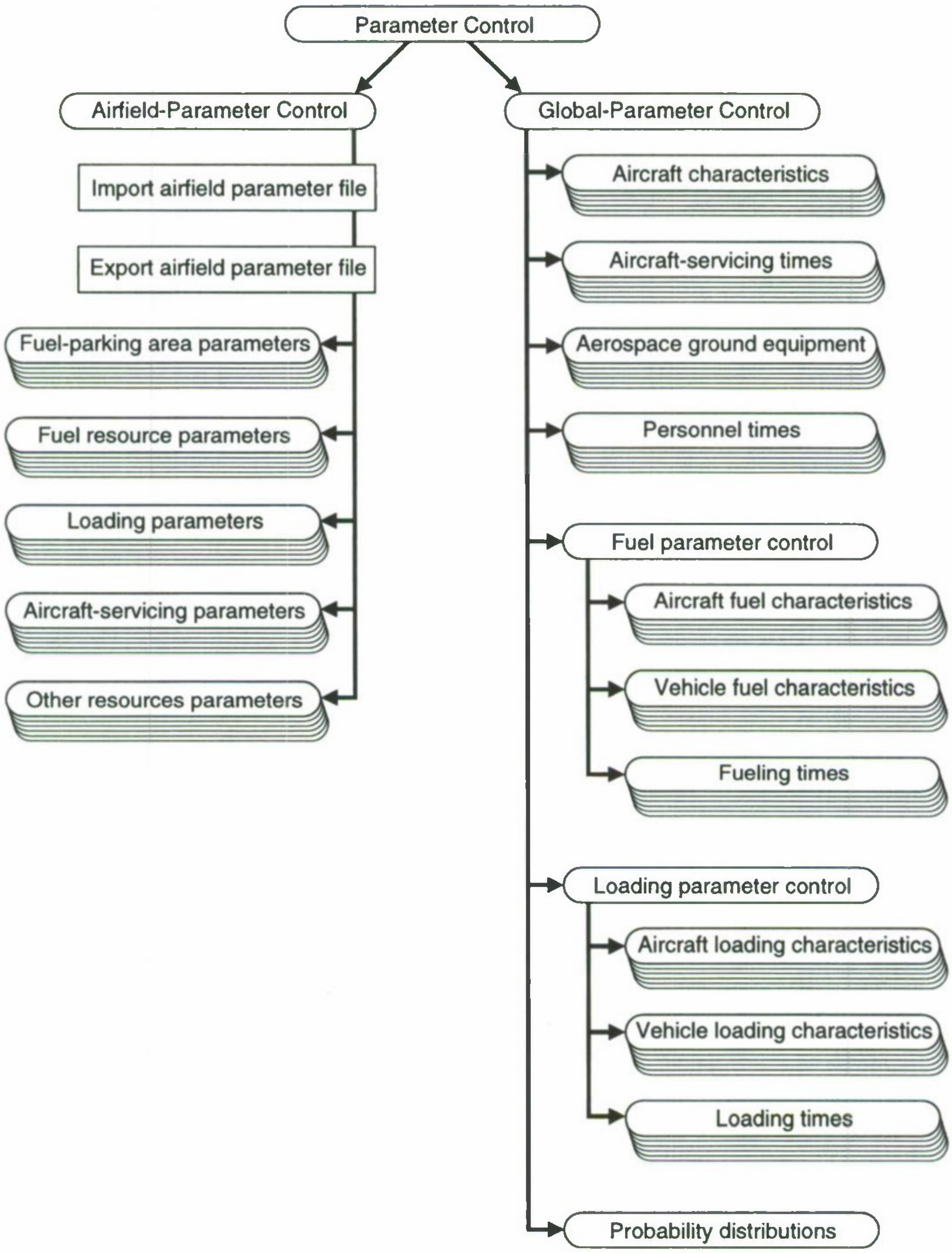

Figure 6.4—Worksheets Holding Parameters

RAND MR700-6.5

Parking and Hydrant-Fueling Parameters

	FPA #1	FPA #2	FPA #3	FPA #4	FPA #5	FPA #6
Designation	A	B	C			
Parking service time (hrs/day)	24	24	24	0	0	0
Capacity						
C-130	3	8	5	0	0	0
C-141	3	8	5	0	0	0
C-5	0	5	0	0	0	0
C-17	3	8	5	0	0	0
KC-10	0	5	0	0	0	0
KC-135	3	8	5	0	0	0
747	0	5	0	0	0	0
Cxx	0	0	0	0	0	0
Cyy	0	0	0	0	0	0
Hydrant fueling						
# aircraft can fuel at once	0	5	0	0	0	0
Fueling rate per aircraft (gal/min)	0	500	0	0	0	0
Availability (hr/day)	0	24	0	0	0	0
Distance (ft) to fuel fill-stands	9,000	4,500	1,500	0	0	0
Distance (ft) to cargo terminal/storage	500	2,000	8,000	0	0	0
Distance (ft) to pax terminal/holding	8,000	1,000	5,000	0	0	0

Return to Airfield-Parameter Control

Figure 6.5—The Fuel-Parking-Area (FPA) and Hydrant-Fueling Parameters Data Screen

Number of aircraft. The user then selects the number of aircraft to be assigned to this mission. The menu displays integers from 1 to 20, then in increments of 5 and (later) 25 up to 200.

Aircraft type. The user then selects the type of aircraft to be assigned to this mission. This menu displays the names of the seven types of aircraft recognized in ACE: C-130, C-141, C-5, C-17, KC-10, KC-135, and 747. Two additional types, Cxx and Cyy, are available for customization when nonstandard aircraft need to be evaluated.

Aircraft configuration. The user then selects the configuration for the above type of aircraft assigned to this mission. The menu displays our three standard configurations: maximum passengers, maximum cargo, and mixed.

Profile foreground operations. The user then selects the ground-servicing profile for the aircraft assigned to this mission. The menu displays our servicing profiles: full service and quick turn.

The user then pushes the "Setup" button, which instructs ACE to locate the parameters associated with the specified aircraft, configuration, and profile, and to copy those parameters into the ACE_COMP.XLS workbook and into the lower menus in the Mission screen.

RAND MR700-6.6

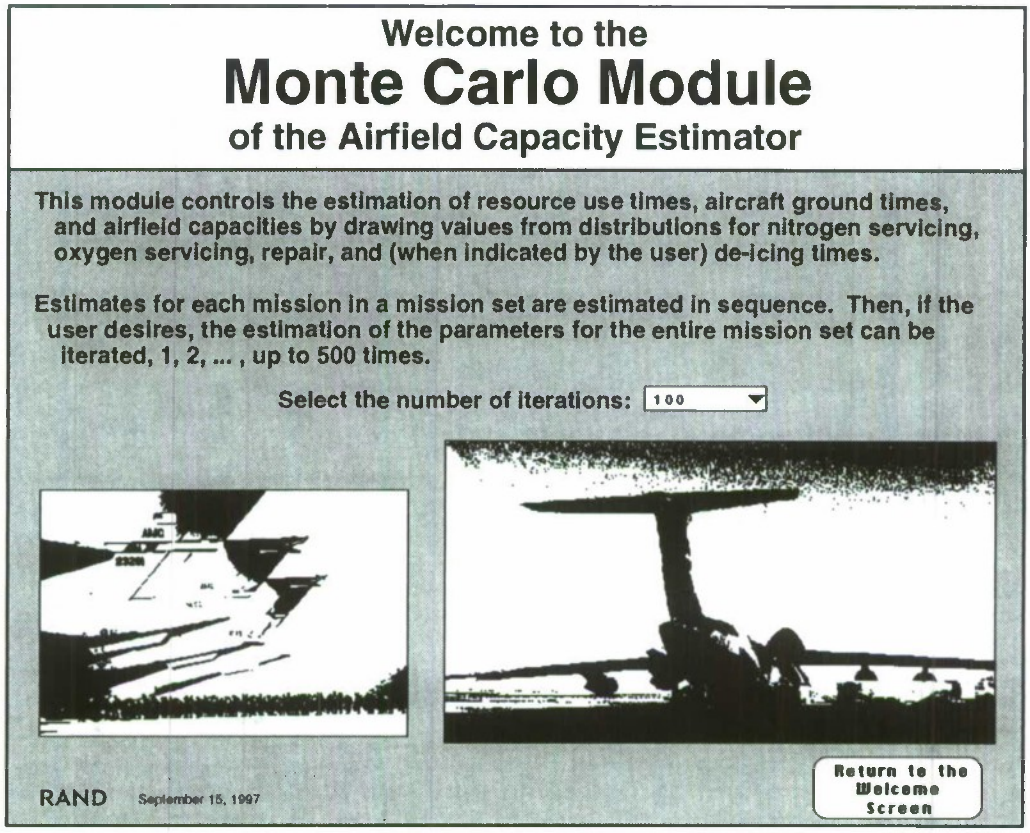

Figure 6.6—The Monte Carlo Setup Screen

The Lower Menus

The user then specifies the scope and intensity of the ground-servicing operations.

Quantity of fuel. The user first selects the quantity of fuel, in pounds, to be transferred into each aircraft assigned to the mission. The menu displays 7 to 10 evenly spaced choices appropriate to the size and fuel efficiency of the selected aircraft. For example, the choices for C-17s are 0, 25,000, 50,000, 75,000, 100,000, 125,000, 150,000, and 175,000.

Fuel transfer must be isolated. The user then allows or disallows loading and repair operations to take place during fuel transfer. Selection of the "yes" option requires other operations to be suspended while fuel is being transferred into the aircraft; selection of the "No" option allows loading and repair to be conducted simultaneously with the fuel transfer.

Passenger loading. The user then indicates the number of passengers to be off-loaded and/or on-loaded. The menu displays 8 to 10 evenly spaced choices appro-

RANDMR700-6.7

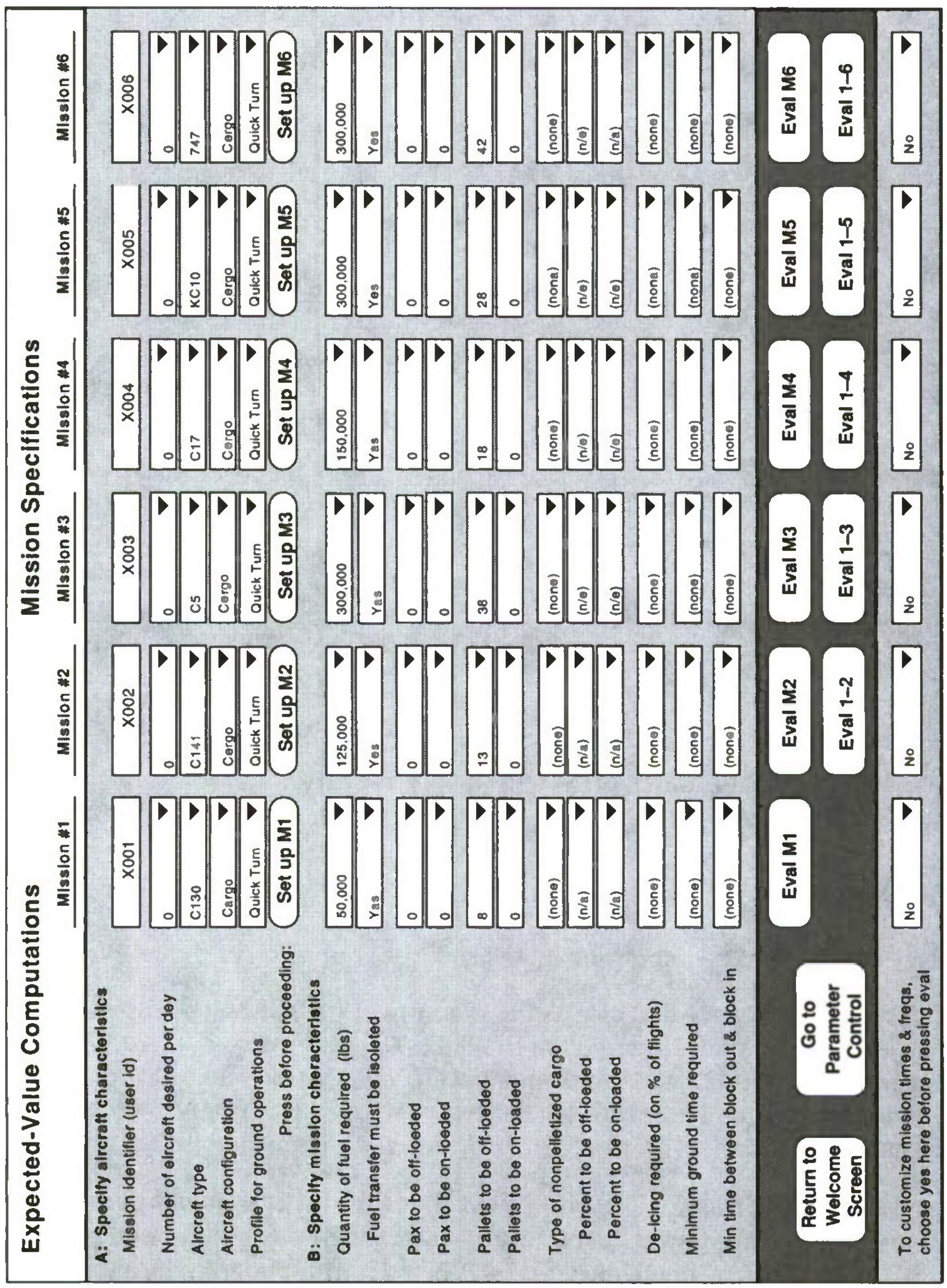

Figure 6.7—The Mission Screen

priate to the aircraft and configuration selected above. For example, the choices for C-17s are 0, 15, 30, 45, 60, 75, 90, and 102.

Pallet loading. The user then indicates the number of pallets to be off-loaded and/or on-loaded. The menus display 6 to 10 evenly spaced choices appropriate to the aircraft and configuration selected above. For example, the choices for C-17s are 0, 3, 6, 9, 12, 15, and 18.

Nonpalletized cargo. The user then specifies whether oversized and outsized cargo will be off-loaded or on-loaded, and how much. The choices here are limited substantially by previous designations of aircraft type, aircraft configuration, and pallet quantities. Some aircraft—KC-10s, KC-135s, and 747s—can carry no nonpalletized cargo; others—C-130s and C-141s—can carry small oversized cargoes but no large oversized or outsized cargoes. And when the user specifies the loading of pallets as well as NPC, the off-loading or on-loading of a partial load of pallets diminishes the possible NPC loads proportionately.

De-icing. The user then specifies whether de-icing will be needed on any of the aircraft assigned to the mission and, if so, to what percentage of those aircraft. Choices are none, 25 percent, 50 percent, 75 percent, and all flights.

Minimum ground time. The user then specifies a minimum ground time, if desired. This can be entered for any type of mission, but becomes operational only for those missions with the full-service profile. Choices are hourly increments from 0 through 24, 36, and 48.

Open time. Finally, this is where the user specifies whether to set aside some open time between aircraft for the parking spots to allow for inefficiencies in aircraft arrivals. Choices are in 10-minute intervals, from zero to 1 hour.

Then the user can initiate the evaluation of the mission and the estimation of servicing times and resource capacities by pressing the Eval button, or can branch to the ACE_COMP.XLS workbook to customize the times or frequencies of any of the ground operations, by pressing the bottom-most button for the mission.[3]

Combinations of Missions

The Mission screen allows up to six missions at a time to be specified and evaluated. But when more than one is to be specified and evaluated, the setup should proceed, as indicated above, from top to bottom for mission 1, then from top to bottom for mission 2, etc.

Note the two rows of evaluation buttons near the bottom of the screen. Each mission has a specific evaluation button, and below that is a button allowing the sequential evaluation of several missions. That is, the user can specify mission 1, evaluate it, and then specify mission 2 and evaluate it, and so on. Or the user can specify several

[3]Both of these options are discussed in Appendix F.

missions and then evaluate them all by pressing the lower Eval button under the highest-numbered mission to be evaluated.

"And" Missions

The Eval button for mission 1 initializes the airfield-resource availabilities before beginning to evaluate that mission. The final step in the evaluation of that (and every) mission is to set aside the resources needed to service the (number of) aircraft associated with that mission. So the airfield resources available to service aircraft associated with mission 2 are those available at the airfield less those used in servicing aircraft associated with mission 1, and likewise for missions 3, 4, 5, and 6.

By specifying positive integers for the quantity of aircraft associated with, say, missions 1 and 2, the user can make statements such as, "this airfield can service 20 associated with mission 1 *and* 20 with mission 2, *and* have some capacity left over."

"Or" Missions

The user can also estimate the capacity of the airfield resources to support independent missions, to answer the question: What is the total capacity of this airfield to support this mission or that mission, etc.? To do this, the user specifies the missions to be evaluated but specifies that zero aircraft be associated with each mission. As the model evaluates the several missions in turn, it considers all of the airfield resources as being available to service aircraft associated with each mission.[4]

The user can analyze combinations of "and" and "or" missions by specifying the "or" missions first, with zero aircraft, and then specifying the "and" missions, each with a nonzero number of aircraft.

THE OUTPUTS

Pressing an Eval button initiates a sequence of subroutines that move parameters, perform computations, and prepare and position outputs. When those procedures have done their work, ACE presents the user with the Output screen, illustrated in Figure 6.8.

This screen has columns for each of the six possible missions, and each column has three portions. The top portion summarizes the mission specifications. The middle portion presents the estimated aircraft ground time, as well as estimates for the times associated with loading (off-loading plus on-loading) and transferring fuel. Two types of estimates are provided: average and marginal. If all aircraft associated with

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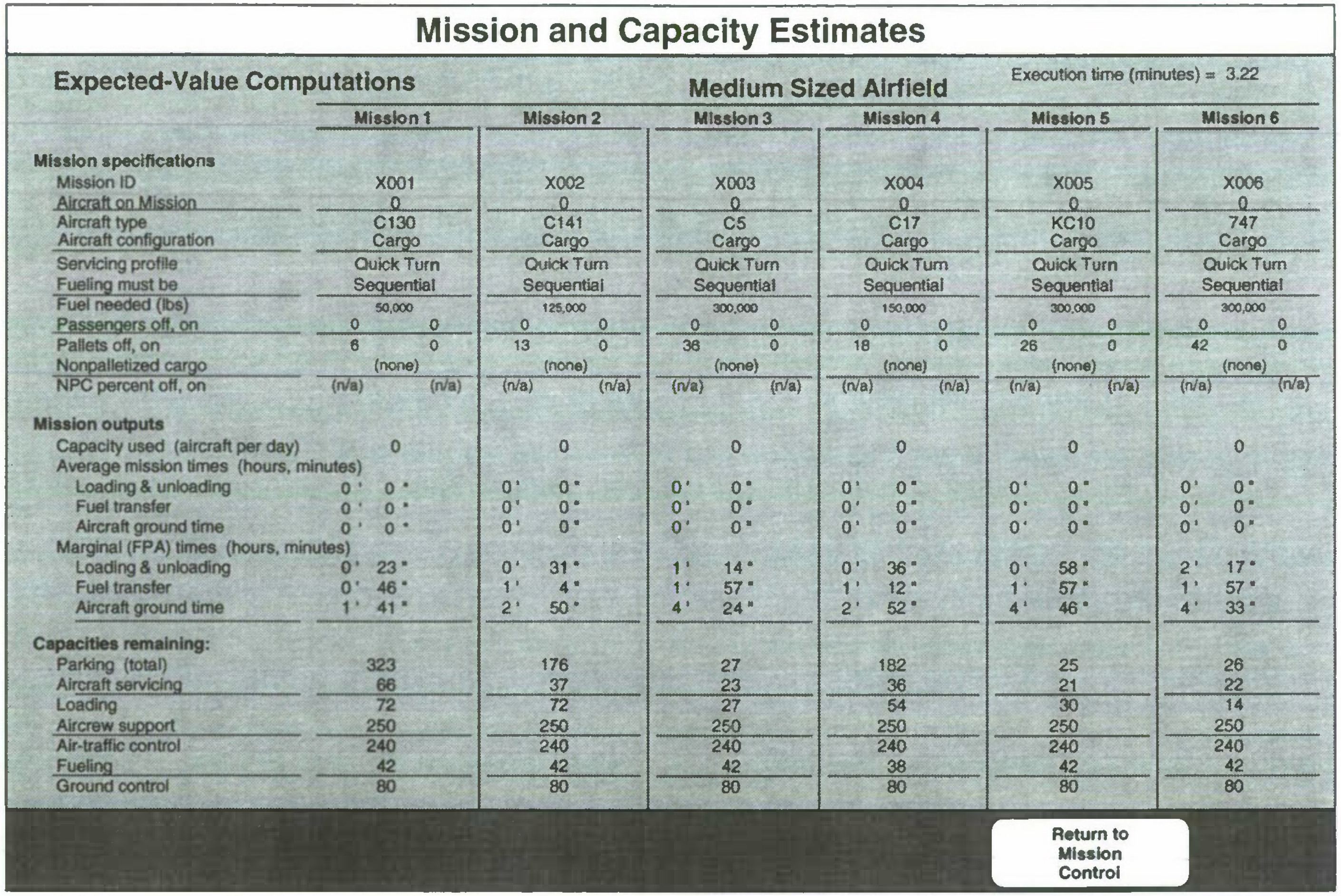
[4]However, in computing residual capacities, the model considers only the service times associated with the best parking ramp—the one with the lowest aircraft service time. These zero-aircraft estimates can be significantly high if (a) the airfield has more than one ramp, (b) the missions involve fueling or the loading of pallets, and (c) the ramps differ significantly in location or fueling rates. Only "and" missions, with some positive number of aircraft requested, can force the model to compute service times for additional ramps. See below and Appendix F.



RAND MR700-6.8

Mission and Capacity Estimates

Expected-Value Computations — Medium Sized Airfield — Execution time (minutes) = 3.22

	Mission 1	Mission 2	Mission 3	Mission 4	Mission 5	Mission 6
Mission specifications						
Mission ID	X001	X002	X003	X004	X005	X006
Aircraft on Mission	0	0	0	0	0	0
Aircraft type	C130	C141	C5	C17	KC10	747
Aircraft configuration	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo
Servicing profile	Quick Turn	Quick Turn	Quick Turn	Quick Turn	Quick Turn	Quick Turn
Fueling must be	Sequential	Sequential	Sequential	Sequential	Sequential	Sequential
Fuel needed (lbs)	50,000	125,000	300,000	150,000	300,000	300,000
Passengers off, on	0 0	0 0	0 0	0 0	0 0	0 0
Pallets off, on	6 0	13 0	36 0	18 0	26 0	42 0
Nonpalletized cargo	(none)	(none)	(none)	(none)	(none)	(none)
NPC percent off, on	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)
Mission outputs						
Capacity used (aircraft per day)	0	0	0	0	0	0
Average mission times (hours, minutes)						
Loading & unloading	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"
Fuel transfer	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"
Aircraft ground time	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"	0' 0"
Marginal (FPA) times (hours, minutes)						
Loading & unloading	0' 23"	0' 31"	1' 14"	0' 36"	0' 58"	2' 17"
Fuel transfer	0' 46"	1' 4"	1' 57"	1' 12"	1' 57"	1' 57"
Aircraft ground time	1' 41"	2' 50"	4' 24"	2' 52"	4' 46"	4' 33"
Capacities remaining:						
Parking (total)	323	176	27	182	25	26
Aircraft servicing	66	37	23	36	21	22
Loading	72	72	27	54	30	14
Aircrew support	250	250	250	250	250	250
Air-traffic control	240	240	240	240	240	240
Fueling	42	42	42	38	42	42
Ground control	80	80	80	80	80	80

Figure 6.8—The Output Screen

a mission can be serviced on the same ramp, the average and marginal estimates will be the same. But if two or more ramps are needed, and transport (fuel trucks, buses, or pallet transports) is required, the estimates of the marginal servicing times will probably be longer than the estimates of the average times. If zero aircraft quantity is associated with any mission, the average times recorded for that mission will be zero.

The bottom portion of each column presents the estimates of capacity for the airfield, by function. Estimates are presented for parking, servicing, loading, aircrew support, air-traffic control, fueling, and ground control. The lowest of these capacities represents the binding constraint and is "the capacity of the airfield." All of these capacities are labeled "capacities remaining," and that is what they represent. If a mission has zero aircraft associated with it, and if it is mission 1, the capacity estimates represent the total capacity of the airfield for supporting aircraft associated with that type of mission. If a mission has zero aircraft associated with it, but one or more missions with higher priority (that is, with a lower mission number) do have quantities of aircraft associated with them, then the estimates represent the capacity of the airfield resources remaining after those higher-priority missions have been supported.

If a mission has aircraft, then the capacities reported in the bottom portion of the column represent the capacities remaining after those aircraft, and all aircraft associated with higher-priority missions, have been supported. And these capacities are represented in terms of the aircraft and servicing specified for this particular mission. If another mission is then specified, it may be more difficult or less difficult to support than the mission in question, and the capacity of those remaining resources for the latter mission may be greater or lesser.[5]

All capacity estimates are expressed in aircraft per day (of the specified type and configuration, on the specified ground-servicing profile, and with the specified mission characteristics). The top portion of the output column for a mission includes the number of aircraft per day the user desires to assign to the mission. The middle portion of the output column shows the number of aircraft that the model estimates could be assigned to the mission. If no constraints have been reached, that number will be the same as the number in the top portion. If one or more constraints have become binding, the number will represent the capacity of the airfield to support that mission using all of its resources, less those set aside for higher-priority missions. The bottom portion of the column shows the remaining capacities, if any. When the capacity of the airfield is reached, one or more of the entries in the lower portion will be zero, and the program will not attempt to evaluate any remaining missions.

Finally, the upper-right corner of the Output screen shows the elapsed time, in minutes, of the last run, whether it evaluated one mission or six missions. Currently, most evaluations of small- to medium-sized missions, with up to 20 or so aircraft,

[5]That is, capacities do not sum over missions; only times, resources, and their use sum (and decrement) over aircraft and over missions.

take approximately half to three-quarters of a minute on a 120-megahertz Macintosh and about one-quarter of a minute on a 166-megahertz PC.

Other output screens provide additional information on mission results. And the spreadsheets themselves allow further investigation of interesting or anomalous results.

The Output screen shown in Figure 6.8 summarizes the products of the expected-value computations. It also summarizes the final iteration of a Monte Carlo run. Figures 6.9 and 6.10 show the screens developed to display and summarize the multiple runs associated with the Monte Carlo analysis.

Screen 6.9 shows the "ROut" (run output) screen associated with a one-iteration, 25-aircraft, Monte Carlo mission. It lists the servicing and repair-time draws for each aircraft, shows several run and capacity indicators, identifies the least ground time–associated parking ramp, and then shows summary statistics—the mean and standard deviation—for the draws and the resulting estimates of aircraft ground time.

Figure 6.10 shows a truncated version of the "IOut" (iteration output) screen associated with a 100-iteration run of two missions—one requesting five C-17s and the second requesting five C-5s. It shows the number of aircraft accepted and the average ground times for each iteration of the mission set, the capacities remaining after each iteration, and, at the bottom, summary statistics for the iterations.[6]

[6]Here, as elsewhere, the estimates of remaining capacities are based on the last-estimated servicing times. In this case, it is the final draw (for the last aircraft) of the second mission. Portions of the ROut and IOut reruns are included as Tables S.4 and S.5 in the Summary.

RAND MR700-6.9

3	4	5	6	7	8	9	10	11
	Time (in minutes) Drawn For:							
Aircraft Number	Nitrogen Servicing	Oxygen Servicing	Repair	De-icing	Aircraft Ground Time	Quantity of Aircraft Still Needed	Capacity of Best Area	Number of Best Area
1	0	0	0	0	161	24	34	2
2	0	0	0	0	161	23	33	2
3	0	0	0	0	161	22	33	2
4	0	0	0	0	161	21	32	2
5	0	0	0	0	161	20	32	2
6	0	45	0	0	206	19	29	2
7	0	0	0	0	161	18	30	2
8	0	0	0	0	161	17	30	2
9	0	0	0	0	161	16	29	2
10	0	0	0	0	161	15	29	2
11	0	0	8	0	161	14	28	2
12	0	45	0	0	206	13	24	2
13	0	0	8	0	161	12	26	2
14	0	0	0	0	161	11	25	2
15	0	45	0	0	206	10	21	2
16	15	45	0	0	221	9	19	2
17	15	45	0	0	221	8	18	2
18	15	0	0	0	176	7	21	2
19	0	0	96	0	185	6	19	2
20	0	0	0	0	161	5	19	2
21	0	0	0	0	161	4	18	2
22	0	45	0	0	206	3	15	2
23	0	45	0	0	206	2	14	2
24	0	0	0	0	161	1	15	2
25	0	0	8	0	161	0	14	2
Average	1.80	12.60	4.80	0	177			
St Dev	4.97	20.62	19.18	0.00	22.57			

Figure 6.9—ROut Screen Associated with 25-Aircraft Monte Carlo Run

RAND MR700-6.10

Airfield Estimates by Iteration

Iteration	Number of Aircraft Accepted and Average Aircraft Ground Time, by Mission: Mission #1		Mission #2		Mission #3		Mission #4		Mission #5		Mission #6		Capacity Remaining After Mission Evaluations				
	Aircraft	AAGT	Aircraft	AAGT	Aircraft	AAGT	Aircraft	AAGT	Aircraft	AAGT	Aircraft	AAGT	Parking	Svcing	Loading	Fueling	Other
1	5	170	2	252									26	0	24	46	9999
2	5	161	3	237									22	0	23	45	9999
3	5	161	3	247									25	0	23	45	9999
4	5	170	3	237									25	0	23	45	9999
5	5	170	2	267									26	0	24	46	9999
6	5	173	3	237									25	0	23	45	9999
7	5	170	2	252									26	0	24	46	9999
8	5	167	3	237									25	0	23	45	9999
9	5	161	3	247									25	0	23	45	9999
10	5	169	3	237									25	0	23	45	9999
11	5	164	3	247									25	0	23	45	9999
12	5	164	3	247									25	0	23	45	9999
13	5	173	3	237									23	0	24	46	9999
14	5	173	2	237									23	0	24	46	9999
15	5	170	2	252									26	0	24	46	9999
16	5	170	3	237									25	0	23	45	9999
17	5	173	2	252									26	0	24	46	9999
18	5	176	2	252									23	0	24	46	9999
19	5	170	2	237									23	0	24	46	9999
20	5	182	2	252									26	0	24	46	9999
21	5	167	3	237									22	0	23	45	9999
22	5	170	2	252									23	0	24	46	9999
23	5	188	2	237									26	0	24	46	9999
24	5	161	3	247									22	0	23	45	9999
25	5	179	2	237									26	0	24	46	9999
91	5	173	2	237									20	0	24	46	9999
92	5	161	2	252									23	0	24	46	9999
93	5	173	2	252									22	0	24	46	9999
94	5	170	2	252									23	0	24	46	9999
95	5	164	3	237									22	0	23	45	9999
96	5	179	2	252									23	0	24	46	9999
97	5	170	2	252									26	0	24	46	9999
98	5	170	2	252									26	0	24	46	9999
99	5	164	3	247									25	0	23	45	9999
100	5	173	3	237									25	0	23	45	9999
Average	5.0	169.8	2.4	247.6									24.1	0.2	23.5	46.0	9999
St Dev	0.00	7.04	0.49	10.80									1.69	0.19	0.40	0.48	0.00

NOTE: A "9999" indicates that resource is unlimited.

Figure 6.10—IOut Screen Associated with 100-Iteration Monte Carlo Run

Chapter Seven

CONCLUSIONS AND RECOMMENDATIONS

Our research indicates that each airfield is unique:

- Each has unique aircraft-parking areas
- Each has unique fueling facilities
- In general, each has a unique set of airfield resources.

If increased operations are planned, many of those resources can be augmented; however, such resources as the ramps and hydrants remain basically fixed, at least in the short run. Airfields support a variety of distinct missions, each mission involving a particular number of aircraft of a particular type and configuration, and each mission requires a particular sequencing and intensity of ground-servicing operations. Therefore, each combination of airfield and mission results in a unique expression of airfield capacity. When several missions are requested, the capacity is even more complex, depending on the needs and priorities of each mission.

We evaluate airfield capacity by relating resources to ground-servicing tasks and operations, and then by estimating resource-servicing times and aircraft ground times, using several types of data. The current implementation uses single-valued representations of resource inventories and availabilities and of many task and operation times. Better data, representing more-current, empirically derived distributions of those availabilities and times, would, of course, provide better estimates.

Nevertheless, in evaluations and comparisons made to date, ACE's estimates of airfield capacities appear to be consistent with experts' expectations. Because airfields seldom operate at full capacity in peacetime and because appropriate historical data are not available, we have not been able to compare ACE's estimates with airfields' actual maximum throughputs.

Our estimates show wide differences in times and capacities for different types of missions, for different levels of operations, and for different sets of resources. The nature of airfield operations suggests that this range of capacities is probably to be expected, and statements concerning "average" capacity—over aircraft type, mission type, or airfield type—should be viewed with skepticism.

Finally, ground-servicing operations are often structured in complex, nonlinear ways. This nonlinearity can cause small differences in resources or mission specifi-

cations to make large differences in servicing times and capacities, or to have little or no effect.

These findings, along with the knowledge gained while conceptualizing and developing the model, and the subsequent perusal of hundreds of estimates produced for different types of aircraft, airfields, and stopovers, lead to our recommendations:

- We recommend, first, that planners and analysts discontinue the use of standard MOGs and standard ground times, because (a) so many factors potentially and commonly influence airfield capacity, (b) the influence of resources on capacity is often decidedly nonlinear, and (c) models like ACE are now so user-friendly and quick to run. Instead, planners and analysts should consider carefully (a) the servicing, fueling, and loading operations needed for each mission stopping at each airfield and (b) the major ground resources available at each airfield.
- Second, because airfield-capacity estimates are important in planning future forces and future operations, and in responding to current contingencies, we recommend that the mobility community undertake near-term data-collection efforts to derive and standardize empirical distributions of times for aircraft repair and for the availability (working time) of the major pieces of ground-support and material-handling equipment .

Efforts to validate and refine the model should continue.

NOTATION

General

A_i, A_i	Availability of resource i
$\mathrm{A}_{i,j}$	Availability of the jth variety of the ith type of resource
C	Capacity of the airfield
C_i	Capacity of resource i
R_i, R_i	Quantity of resource i
$\mathrm{R}_{i,j}$	Quantity of the jth variety of the ith type of resource
S_i	Service time of resource i
$X^{\mathrm{c}}_{i,j}$	Capacity of the jth variety of the ith type of resource
$X^{\mathrm{r,\,in}}_{i,j}$	Transfer rate (in) of the jth variety of the ith type of resource
$X^{\mathrm{r,\,out}}_{i,j}$	Transfer rate (out) of the jth variety of the ith type of resource
$X^{\mathrm{s}}_{i,j}$	Speed of the jth variety of the ith type of resource
α_k	Probability of operation k being needed
β_k	Dummy variable for needing operation k

Servicing

a, b, and c	Subscripts representing the servicing intervals during which operations can be performed concurrently
a/c	Aircraft
AST	Aircraft-servicing time
AGT	Aircraft ground time
BI	Block-in time
BO	Block-out time
DI	De-icing time
D_{c}	Off-load cargo time
D_{p}	Off-load personnel time

f, t	Superscripts, referring to the "full-service" and "quick-turn" ground-servicing profiles
F_1	Pre-fuel time
F_2	Transfer-fuel time
F_3	Post-fuel time
G^f, G^t	General-servicing time
GPU	Ground-power unit
I_1^f	Inspection, post-flight, time
I_2^f	Inspection, pre-flight, time
I^t	Inspection, through-flight, time
M^f, M^t	Maintenance, or repair, time
N^f, N^t	Nitrogen-servicing time
O^f, O^t	Oxygen-servicing time
OT	Open time
p	Subscript for passengers
P	Subscript for parking area
$T_{k,j,i}$	Time, where k represents the servicing resources, j indexes over the ground-servicing operations, and i indicates the type of aircraft assigned to the mission
U_c	On-load cargo time
U_p	On-load personnel time
Fueling	
FPA	Superscript for fuel parking area
$T^F_{h,\text{ drive}}$	Time to drive the hydrant-service vehicle (HSV) to the aircraft
$T^F_{h,\text{ hookup}}$	Time to set up the aircraft and HSV for fueling
$T^F_{h,\text{ transfer}}$	Time to transfer fuel into the aircraft
$T^F_{h,\text{ unhook}}$	Time to secure aircraft and HSV from fueling
$T^F_{t,\text{ drive}}$	Time to drive fuel truck from fill stand to aircraft
$T^F_{t,\text{ hookup}}$	Time to position and hook up truck to aircraft
$T^F_{t,\text{ refill}}$	Time to fill truck at fill stand
$T^F_{t,\text{ secure}}$	Time to secure aircraft and truck from fueling
$T^F_{t,\text{ transfer}}$	Time to transfer fuel from one truck to an aircraft
$T^F_{t,\text{ unhook}}$	Time to unhook and move truck from aircraft

$X^{F}_{h,\ \text{transfer rate}}$	Effective transfer rate into aircraft for hydrant fueling
$X^{F}_{t,\ \text{at once}}$	Number of trucks that can effectively pump fuel into the aircraft at the same time
$X^{F}_{t,\ \text{avail}}$	Estimate of trucks available for servicing each aircraft
$X^{F}_{t,\ \text{loads}}$	Number of truckloads of fuel required
$X^{F}_{t,\ \text{transfer rate}}$	Effective transfer rate into aircraft for truck fueling

Loading

$T^{L}_{b,\ \text{set up}}$	Time required for setting up aircraft before on-loading or off-loading of personnel
$T^{L}_{c,\ a/c,\ d}$	Time to off-load the transporter with pallets from the aircraft
$T^{L}_{c,\ a/c,\ u}$	Time to on-load pallets from the transporter to the aircraft
$T^{L}_{c,\ n,\ \text{set up}}$	Time required for setting up aircraft before on-loading or off-loading of nonpalletized cargo
$T^{L}_{c,\ p,\ \text{set up}}$	Time required for setting up aircraft before on-loading or off-loading of pallets
$T^{L}_{c,\ \text{term},\ d}$	Time to off-load pallets from the transporter at the terminal
$T^{L}_{c,\ \text{term},\ u}$	Time to on-load the transporter with pallets at the terminal
$T^{L}_{\text{set up}}$	Time required for setting up aircraft before *any* on-loading or off-loading may commence
$X^{L}_{c,\ \text{loads, down}}$	Number of transporter loads of cargo to be off-loaded
$X^{L}_{c,\ \text{loads, up}}$	Number of transporter loads of cargo to be on-loaded
WBEL	Subscript for wide-body elevator loader

NOTE: Athough the words used for loading in this report are *off-loading* and *on-loading*, we use terms *D* (for *downloading*) and *U* (for *uploading*), respectively, to avoid confusion of *on* and *off* with the *O* for *oxygen servicing*. Table C.1 contains terms for each of 17 operations.

Appendix B

DETAILS OF THE APPROACH

The basic relationship between airfield resources and the airfield's capacity is taken to be

$$C = \text{Min}\left(R_i * A_i / S_i\right) \quad \text{over } i = 1,\ldots,n \tag{B.1}$$

where C stands for the capacity of the resources at the airfield to service aircraft (*capacity* is expressed as the number of aircraft of a particular type requiring a particular set of services that can be performed at the airfield in one day), R_i represents the quantity of a particular resource, A_i represents the hours per day that the resource is available, and S_i stands for the time required of that resource in servicing one aircraft. The user inputs information on the resources and their availability, and on the tasks that must be performed to support a particular mission. The model estimates the service times associated with those tasks and resources, and then estimates the number of aircraft the airfield and its resources can support in a day.

We estimate airfield capacity in three steps:

- First, we calculate the total service time available for each resource considered—i.e., the number of units of the resource present (e.g., the number of fuel trucks or k-loaders) times the average amount of time each unit is available per day.
- Second, we calculate the time needed from each resource to service each type of mission to be included in the day's throughput for the base. These times depend on the type of aircraft; the types and amounts of cargo to be handled, if any; the number of passengers to be on-loaded and off-loaded, if any; the amount of fuel to be loaded, if any; and the types of repair or other services (e.g., liquid oxygen or de-icing) to be provided, if any.
- Third (and repetitively), in proportion to the service time needed for a particular mission type, we decrease the total service time available from each resource. For example, if the airfield accommodates one type of C-141 mission that takes 3 hours of k-loader time, and if 10 such missions are to be included in the day's throughput, then 30 hours of k-loader time is subtracted from the total number of k-loader hours available that day. This step can be repeated at will, adding more missions until the available time of one or more of the airfield's resources is exhausted.

While this approach is quite simple in concept, it is somewhat more complex to accomplish in practice. For example, the service times calculated in the second step can depend on (a) where aircraft are parked (e.g., affecting the amount of k-loader time spent driving between aircraft and the aerial-port area); (b) the cargo on-loading/off-loading times affect the time that crew chiefs (aircraft-servicing specialists) spend at the aircraft; and (c) mission-specific requirements for sequential or concurrent accomplishment of some tasks (e.g., fueling and cargo on-loading/off-loading) affect aircraft ground times and, hence, consumption of available parking space.

The following examples illustrate the basic methods of handling such interrelationships.

MULTIPLE RESOURCES

Suppose we have only two types of resources, each of which performs one task on an aircraft, and suppose that one task must be completed before the other can be started. Then

$$C = \begin{cases} C_1 = R_1 * A_1 / S_1 \\ C_2 = R_2 * A_2 / S_2 \\ C_P = R_P * A_P / (S_1 + S_2) \end{cases} \tag{B.2}$$

where the subscripts refer to the different resources. C_1 is the capacity of the first resource, expressed in the number of aircraft it can service per day, C_2 is the capacity of the second resource, and C_P expresses what we call the "parking capacity." Each aircraft serviced at the airfield uses resource 1 for S_1 minutes, it uses resource 2 for S_2 minutes, and it must remain on the ground, taking up space and time, for $S_1 + S_2$ minutes. This final term represents the heart of our modeling approach.

As a second example, suppose we need the same two resources working on the aircraft, but they can perform their tasks *concurrently*. Then

$$C = \mathrm{Min} \begin{cases} C_1 = R_1 * A_1 / S_1 \\ C_2 = R_2 * A_2 / S_2 \\ C_P = R_P * A_P / \mathrm{Max}(S_1, S_2) \end{cases} \tag{B.3}$$

Note that the longer of the two tasks represents the parking time, or ground time, rather than the sum of the two tasks, and that only the parking equation differs according to whether the tasks performed by the two types of resources can be performed concurrently or must be accomplished sequentially.

MULTIPLE USES

Now suppose we have only one type of resource, but that it must perform two distinct tasks on each aircraft. Consider the capacity of a single resource, such as a

ground-power unit (GPU) that supplies electrical current to operate both support equipment and some subsystems of the aircraft as it sits at the airfield. Suppose each aircraft requires two servicing operations, that each operation takes a set amount of time, and that each requires that a GPU be supporting the aircraft. If the operations are performed concurrently, then the time the GPU is needed is equal to the time of the longer operation:

$$C_{GPU} = R_{GPU} \quad * \quad A_{GPU} / \mathrm{Max}\left(S_{GPU,a},\ S_{GPU,b}\right) \tag{B.4}$$

But if the operations must be performed sequentially, the service time of the GPU is the sum of the two service times. That is,

$$C_{GPU} = R_{GPU} \quad * \quad A_{GPU} / \left(S_{GPU,a} + S_{GPU,b}\right) \tag{B.5}$$

Appendix C details the operations, and the protocols for their sequencing, that we have incorporated into ACE.

MULTIPLE PARKING AREAS

Now consider some resource that cannot perform two services at once—such as manpower—and two parking areas. And assume that the manpower can be allocated among the work in either parking area, but that the parking or ramp space is specific to each area and cannot be moved. To determine the maximum capacity of the airfield for this case, we must allocate the manpower between the two parking areas in some optimal manner. To do so, we first estimate the aircraft ground time that would be required if the aircraft were serviced in each parking area. Call these estimates S_P^1 and S_P^2.

We choose the parking area with the shortest S_P^i, call it $\hat{S}_P$, to utilize first. Then we compute the capacity of that area, looking at both the parking and the manpower resources:

$$\hat{C} = \mathrm{Min}\begin{cases} \hat{C}_m = R_m \quad * \quad A_m / \hat{S}_m \\ \hat{C}_P = \hat{R}_P \quad * \quad \hat{A}_P / \hat{S}_P \end{cases} \tag{B.6}$$

If this capacity is limited by the manpower resource, then $\hat{C}$ represents the capacity of the entire airfield. But if all of the manpower is not being used in that parking area, then we must calculate an adjusted, or marginal, capacity for the other area, given that the more-efficient area is already being used to capacity.

Assume for this example that area 1 has the higher capacity and that that capacity is limited by parking rather than by manpower. Then the amount of the manpower resource-time used in area 1 is $C_P^1 * S_m^1$, and we can express the combined capacity of areas 1 and 2 as

$$C = C_p^1 + \mathrm{Min}\begin{cases} C_m^2 = \left[\left(\mathrm{R_m} * \mathrm{A_m}\right) - \left(C_p^1 * S_m^1\right)\right] \Big/ S_m^2 \\ C_p^2 = \mathrm{R}_p^2 * \mathrm{A}_p^2 \,/\, S_p^2 \end{cases} \tag{B.7}$$

MULTIPLE MISSIONS

The final example in this appendix illustrates how we deal with airfields servicing aircraft engaged in different missions. To keep it simple, we assume that the airfield contains only one type of resource and one parking area, and that the resource performs only one operation on each aircraft. Say the operation is fueling, and suppose that aircraft on one mission are flying farther or simply require more fuel than aircraft on the other mission. As a result, the service times will differ. We also ignore parking in this example. The subscripts now designate the mission types.

If the airfield were servicing only aircraft engaged in the first type of mission, we could express its capacity as

$$C_1 = \mathrm{R} * \mathrm{A} \,/\, S_1 \tag{B.8}$$

And if it were servicing only aircraft engaged in the second type of mission, we could express the capacity as

$$C_2 = \mathrm{R} * \mathrm{A} \,/\, S_2 \tag{B.9}$$

When the airfield services aircraft engaged in both types of missions we have the expanded equation set

$$\begin{aligned} C_1 &= \mathrm{R} * A_1 / \mathrm{S}_1 \\ C_2 &= \mathrm{R} * A_2 / \mathrm{S}_2 \\ \mathrm{A} &= A_1 + A_2 \end{aligned} \tag{B.10}$$

where A_1 and A_2 represent the portions of the resource's total availability A (the work time of the resource) devoted to each of the mission types. This problem involves apportioning that availability in order to calculate capacity.

Capacity now is not a unique quantity; it depends on the allocation of the availability A to mission 1 as opposed to mission 2.[1] Our approach is to require deployment planners (the model's users) to sequentially allocate the availability to mission types. That is, first analyze mission type 1, solving the first equation (in Eq. B.10) for C_1, the maximum number of aircraft engaged in mission type 1 that the airfield can service in one day. Then actually allocate a portion of the availability of the airfield resource against that mission type. That is, say "Let's assume we will send $\overline{C}_1$ of mission-type-1 aircraft (where $\overline{C}_1 \le C_1$ and $\overline{C}_1$ is a positive integer) through the airfield on the day in question." That reduces the resource time available for the second

[1] We have four unknowns in three equations.

mission to $R * A - \overline{C}_1 * S_1$. Then investigate how many aircraft engaged in mission type 2 the airfield can (still) handle. That is,

$$C_2 = \left[(R * A) - (\overline{C}_1 * S_1)\right] / S_2 \quad \text{(B.11)}$$

where $\overline{C}_1 * S_1$ represents the portion of the resource time, in minutes per day, allocated to aircraft engaged in mission type 1. If we consider n mission types, this procedure generalizes to

$$C_n = \left[(R * A) - (\overline{C}_1 * S_1) - \ldots - (\overline{C}_{n-1} * S_{n-1})\right] / S_n \quad \text{(B.12)}$$

EQUIPMENT COMPOSITING

When we modeled fuel trucks, pallet transporters, wide-body elevator loaders (WBELs), and passenger buses, we quickly learned that many varieties of each existed, each with differing capacities, speeds, and reliabilities. And we quickly learned that we could not expect to anticipate or prespecify the types that might be in inventory at any particular airfield. Hence, our approach is to specify the several most-prevalent types of military vehicles in each category, to specify one or two civilian types if such exist, and then to allow the user to input information on any other types available at the particular airfield under investigation.

After the user has specified the quantity of the predefined types and the specifications of the other types, the model run begins with computations that aggregate the available vehicles into a normalized quantity of a customized, aggregate, composite vehicle.

That is, if an airfield has one 25k-loader that carries 3 pallets and one 40k-loader that carries 5 pallets, with the 25k-loader available, on average, 20 hours per day and the 40k-loader available, on average, 10 hours per day, we combine them into two composite transporters that carry 3.67 pallets and that are available 15 hours per day.

Formally, we have

$$R_i = \sum_j R_{i,j} \quad \text{(B.13)}$$

for the quantity of the ith composite resource, where $R_{i,j}$ represents the quantity of the jth variety of the ith type of resource. For the availability of the ith composite resource, we have

$$A_i = \sum_j (R_{i,j} * A_{i,j}) / R_i \quad \text{(B.14)}$$

where $A_{i,j}$ represents the availability of the *j*th variety of the ith type of resource. We have

$$X_i^s = \sum_j \left(R_{i,j} * A_{i,j} * X_{i,j}^s\right) \Big/ \left(R_i * A_i\right) \tag{B.15}$$

for the speed of the ith composite resource, where $X_{i,j}^s$ represents the speed of the *j*th variety of the ith type of resource. For capacity of the ith resource, we have

$$X_i^c = \sum_j \left(R_{i,j} * A_{i,j} * X_{i,j}^c\right) \Big/ \left(R_i * A_i\right) \tag{B.16}$$

where $X_{i,j}^c$ represents the capacity of the *j*th variety of the ith type of resource. For the pumping (or transferring-out) rate of the ith composite resource, we have

$$X_i^{r,\,out} = \sum_j \left(R_{i,j} * A_{i,j} * X_{i,j}^{r,\,out}\right) \Big/ \left(R_i * A_i\right) \tag{B.17}$$

where $X_{i,j}^{r,\,out}$ represents the transfer rate out of the *j*th variety of the ith type of resource. And, for the receiving rate of the ith composite resource, we have

$$X_i^{r,\,in} = \sum_j \left(R_{i,j} * A_{i,j} * X_{i,j}^{r,\,in}\right) \Big/ \left(R_i * A_i\right) \tag{B.18}$$

where $X_{i,j}^{r,\,in}$ represents the transfer rate into the *j*th variety of the ith type of resource.

SERVICING EQUATIONS

ACE estimates airfield capacity based on the operations performed on an aircraft from the moment it is marshalled into parking until it is marshalled out. This appendix continues the definition of those operations, the resources required in performing them, and the logic governing the sequencing of the operations. The aircraft-servicing module aggregates the times required for all ground operations, including the times estimated in the fueling and loading modules, which we discuss in Appendices D and E, and identifies which resource constrains the airfield's overall capacity.

Table C.1 lists all the ground operations typically performed on cargo-carrying aircraft.[1] The aircraft-servicing module determines airfield capacity by identifying the operations performed and the corresponding types and amounts of resources required by each aircraft. The occurrence, timing, duration, and concurrency of operations depend on the mission profile, the user's detailed specification of the mission, and on the seven conventions in Table 3.3. We model two mission profiles. The longer, or "full-service," stopover includes post- and pre-flight inspections, several types of servicing, some maintenance (repair) actions, and a minimum ground time to account for scheduling delays, aircrew-rest requirements, or other ground-delay considerations. The shorter, or "quick-turn," stopover entails only a single inspection and typically includes fewer and shorter servicing and repair actions.[2]

We can classify the ground operations into three not mutually exclusive sets. One set includes BI, F_1, F_2, F_3, D_p, D_c, U_c, U_p, and BO, and depends on mission parameters—whether and how much fuel is required, whether and how much cargo and passengers are to be off-loaded, whether de-icing is required or not—but not on the mission profile—whether it is a full-service or a quick-turn stopover. That is, we assume it takes the same amount of time to taxi and park an aircraft, to fuel it, to

[1]By setting specific operations' times to zero, we model austere airfields, where not all of the operations are performed.

[2]For example, although the duration of the average oxygen service is generally independent of mission specification, the number of aircraft requiring this service typically increases for flights with extended ground time. Likewise, aircrews seem less inclined to submit write-ups for short servicing stops, and repairers have greater opportunity to address broken but not flight-critical items during extended servicing. So one would expect the frequency and duration of repair to be greater for aircraft in the extended-service profile than for those in the through-flight profile.

Table C.1

Aircraft-Servicing Operations and Notation

Operation	Definition	Full Service	Quick Turn
Block in	For the parking resource, represents the period beginning with the initiation of marshalling the aircraft into parking and ending with engine shutdown. With respect to the personnel and Aerospace Ground Equipment (AGE) resources, adds the actions of preparing the parking spot for block in, as well as those of securing the aircraft after engine shutdown.	*BI*	*BI*
Inspections			
Post-flight	Standard through-flight inspection given to aircraft on brief layover. Performed shortly after engine shutdown.	I_1^f	
Pre-flight	Standard post-flight inspection given to aircraft on extended layover. Performed shortly after engine shutdown but before the aircraft is secured; first of two inspections rendered such aircraft.	I_2^f	
Through-flight	Standard pre-flight inspection for aircraft on extended layover. Performed shortly after unsecuring the aircraft but before engine start, and is the last of two inspections rendered such aircraft (see also post-flight).		I^t
Servicing			
General	Aggregates all remaining service actions unaccounted for by the other service (or inspection) operations.	G^f	G^t
Nitrogen	Servicing the aircraft with nitrogen.	N^f	N^t
Oxygen	Servicing the aircraft with oxygen.	O^f	O^t
Fueling			
Pre-fueling	Actions required to prepare an aircraft for refueling.	F_1	F_1
Fuel transfer	Active fuel-transfer period as determined by the fuel module (excluding the set-up and secure times of the petroleum, oil, and lubricants [POL] personnel).	F_2	F_2
Post-fueling	Actions required to secure the aircraft after fueling.	F_3	F_3
Loading			
Off-load pax	Actions required to safely off-load passengers	D_p	D_p
Off-load cargo	Actions required to off-load cargo	D_c	D_c
On-load cargo	Actions required to on-load cargo	U_c	U_c
On-load pax	Actions required to safely on-load passengers	U_p	U_p
De-icing	Actions of typical de-icing service (i.e., comprehensive removal of light snow and ice). Includes the time personnel and AGE are dedicated to preparing for and securing from de-icing the aircraft.	*DI*	*DI*
Repair	Actions collectively representative of both preventative and restorative maintenance.	M^f	M^t
Block out	For the parking resource, represents the period beginning with the initiation of engine start and ending when the aircraft is marshalled out of parking. With respect to the personnel and AGE resources, adds the actions of preparing for engine start, as well as those of securing the parking spot after block out.	*BO*	*BO*

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NOTE: Although the words used for loading in this report are *off-loading* and *on-loading*, we use terms *D* (for *downloading*) and *U* (for *uploading*) to avoid confusion of *on* and *off* with the *O* for *oxygen servicing*.

unload its cargo, etc., whether the aircraft is in a quick-turn or slower-turn mode. A second set of operations (including the *I*s, the *G*s, the *N*s, the *O*s, and the *M*s) does depend on the type of mission. We assume these operations take longer—because more tasks are accomplished—during full-service stops. A third set of operations (the *N*s, the *O*, and the *M*s) is not required on every mission. We assume these operations are needed only on a percentage of the stopovers, a percentage that can differ for the two mission profiles.

THE EXPECTED VALUE OF AIRCRAFT GROUND TIME

Our ground service includes four operations that are not needed on every aircraft associated with the mission. These are nitrogen servicing, oxygen servicing, repair, and de-icing. We assume they are needed only on a certain percentage (α_1, α_2, α_3, and α_4, respectively) of the aircraft, where α_1, α_2, and α_3 are global variables specific to each type of aircraft, and α_4 is a mission variable specified by the user.

Because the aircraft-ground-time-estimating equation, the other resource-use equations, and the capacity equations themselves are nonlinear, we must evaluate them carefully to ensure that they at least approximate the expected value of the combined operations. To do this, we use Eq. C.1 to normalize and evaluate the aircraft-ground-time equation. We use similarly structured equations, but without the minimum ground-time term, to evaluate the other resource-use times:

$$AGT = \mathrm{Max}\begin{cases} \displaystyle\sum_{\beta_1=0}^{1}\sum_{\beta_2=0}^{1}\sum_{\beta_3=0}^{1}\sum_{\beta_4=0}^{1}\prod_{l=1}^{4}\begin{Bmatrix}\left[1-\beta_l+\left(2\beta_l-1\right)\alpha_l\right] \\ *\ AST\left(\beta_1,\beta_2,\beta_3,\beta_4\right)\end{Bmatrix} \\ \\ \text{Minimum Ground Time} \end{cases} \tag{C.1}$$

where the β_k are binary toggles having values of one or zero, corresponding to the occurrence and nonoccurrence of the four uncertain operations.[3]

EQUATIONS FOR THE MONTE CARLO ANALYSES

The equations for the Monte Carlo estimates are more straightforward, because here we draw random numbers for each probabilistic variable for each aircraft; so, combinations and convolutions such as Eq. C.1 are not necessary. The equation simplifies to

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[3]Equation C.1 represents the summation of 16 different equations to account for the 2^4 possible permutations as a result of the four probabilistic operations: oxygen service, nitrogen service, repair, and de-icing.

$$AGT = \text{Max}\begin{cases} AST \\ \text{Minimum Ground Time} \end{cases} \tag{C.1.1}$$

with similar equations for the other use times. More-sophisticated control of the iterations is necessary, and that will be discussed in Appendix F.

EQUATIONS FOR THE FULL-SERVICE PROFILE

Using the notation of Table C.1 and the conventions of Table 3.3, we express the ground-time equation for an aircraft undergoing a full-service mission profile as

$$AST^{f} = BI + \text{Max}\begin{Bmatrix} I_1^{f} + G^{f} + F_1 \\ D_p + D_c \\ M_a^{f} \end{Bmatrix} + F_2$$

$$+ \text{Max}\begin{Bmatrix} F_3 + \beta_1 N^{f} \\ M_b^{f} \end{Bmatrix} + \beta_2 O^{f}$$

$$+ \text{Max}\begin{Bmatrix} U_c + U_p \\ M_c^{f} \end{Bmatrix} + I_2^{f} + \beta_4 DI + BO \tag{C.2}$$

Equation C.2 reflects the conventions of performing recovery, fuel transfer, oxygen service, de-icing, and launch in isolation, and the conventions that determine when the other operations are performed. Since this expression is for a longer stop, the full-service profile, we also specify that passengers be off-loaded before the cargo is off-loaded and that passengers be on-loaded after the cargo is on-loaded. And we specify that the pre-flight inspection will not begin until all other operations, except possibly for de-icing, have been completed.

We allow for repair to be conducted concurrently with all operations that have not been declared isolated. And we do not require that repair be completed before other operations can begin. We allow repair to continue, as necessary, along with other non-isolated operations.

We define the possible repair segments as

$$M_a^{f} = \text{Min}\begin{cases} \text{Max}\begin{Bmatrix} I_1^{f} + G^{f} + F_1 \\ D_p + D_c \end{Bmatrix} \\ \beta_3 M^{f} \end{cases} \tag{C.2.1}$$

$$M_b^f = \text{Min}\begin{Bmatrix} F_3 + \beta_1 N^f \\ \beta_3 M^f - M_a^f \end{Bmatrix} \quad \text{(C.2.2)}$$

and

$$M_c^f = \beta_3 M^f - M_a^f - M_b^f \quad \text{(C.2.3)}$$

where the a, b, and c subscripts refer to the three working intervals that were illustrated in Figure 3.1. With these specifications, the repair does not unnecessarily extend the a or b block of common servicing time. The c block may be extended if repair turns out to be the long-duration item.

EQUATIONS FOR THE QUICK-TURN PROFILES

Quick turns are less time-consuming than full-service stops. They are usually performed at enroute or off-loading airfields. We have modeled two versions: one in which fuel transfer is isolated, as it always is in the full-service profile, and one in which ground time can be shortened even more by combining fuel transfer with the loading and repair operations.

In these quick turns, we allow not only those repairs that might be needed but also the general and nitrogen servicing and the cargo off-loading and on-loading to be interrupted for fuel transfer (when concurrency is not allowed) and for oxygen servicing (when it is needed). Our equations specifying the component times for these operations allow for shortest-possible ground times.

And, as noted above, if the user specifies that any of the operations are not to be performed for a specific mission, then the times for those operations become zero in the ground-time (and resource-use-time) calculations for those missions.

Quick-Turn with Fuel Transfer Isolated

For the quick turn with fueling isolated, the formulation is

$$AST^t = BI + \text{Max}\begin{Bmatrix} I_1^t + \left(G_a^t + N_a^t\right) + F_1 \\ D_p \\ D_{ca} + U_{ca} \\ M_a^t \end{Bmatrix} + F_2$$

$$+ \text{Max}\begin{Bmatrix} F_3 + \left(G_b^t + N_b^t\right) \\ D_{cb} + U_{cb} \\ M_b^t \end{Bmatrix} + \beta_2 O^t$$

$$+ \text{Max}\begin{Bmatrix} \left(G_c^t + N_c^t\right) \\ U_p \\ D_{cc} + U_{cc} \\ M_c^t \end{Bmatrix} + \beta_4 DI + BO \tag{C.3}$$

In this shorter stop, we require only one inspection and we allow the off-loading and the on-loading of passengers and cargo to take place simultaneously. We also allow the nitrogen servicing and the handling of cargo to be spread over the three segments of ground time.

We represent the component times of the general-servicing and nitrogen-servicing operations as

$$G_a^t + N_a^t = \text{Max}\begin{Bmatrix} \text{Min}\begin{Bmatrix} D_p - \left(I_1^t + F_1\right) \\ \left(G^t + \beta_1 N^t\right) \end{Bmatrix} \\ 0 \end{Bmatrix} \tag{C.3.1}$$

$$G_b^t + N_b^t = 0 \tag{C.3.2}$$

and

$$G_c^t + N_c^t = G^t + \beta_1 N^t - \left(G_a^t + N_a^t\right) - \left(G_b^t + N_b^t\right) \tag{C.3.3}$$

We represent the component times of the repair operation as

$$M_a^t = \text{Min}\begin{Bmatrix} \text{Max}\begin{Bmatrix} I_1^t + \left(G_a^t + N_a^t\right) + F_1 \\ D_p \end{Bmatrix} \\ \beta_3 M^t \end{Bmatrix} \tag{C.3.4}$$

$$M_b^t = \text{Min}\begin{cases} F_3 \\ \left(\beta_3 M^t - M_a^t\right) \end{cases} \quad \text{(C.3.5)}$$

and

$$M_c^t = \beta_3 M^t - M_a^t - M_b^t \quad \text{(C.3.6)}$$

We represent the component times of the cargo–off-loading operations as

$$D_{ca} = \text{Min}\begin{cases} \text{Max}\begin{cases} I_1^t + \left(G_a^t + N_a^t\right) + F_1 \\ D_p \end{cases} \\ D_c \end{cases} \quad \text{(C.3.7)}$$

$$D_{cb} = \text{Min}\begin{cases} F_3 \\ \left(D_c - D_{ca}\right) \end{cases} \quad \text{(C.3.8)}$$

and

$$D_{cc} = D_c - D_{ca} - D_{cb} \quad \text{(C.3.9)}$$

And we represent the component times of the cargo–on-loading operations as

$$U_{ca} = \text{Min}\begin{cases} \text{Max}\begin{Bmatrix} I_1^t + \left(G_a^t + N_a^t\right) + F_1 \\ D_p \end{Bmatrix} - D_{ca} \\ U_c \end{cases} \quad \text{(C.3.10)}$$

$$U_{cb} = \text{Min}\begin{cases} F_3 - D_{cb} \\ U_c - U_{ca} \end{cases} \quad \text{(C.3.11)}$$

and

$$U_{cc} = U_c - U_{ca} - U_{cb} \quad \text{(C.3.12)}$$

Quick-Turn with Concurrent Fuel Transfer

This case is very similar to the isolated fuel-transfer case, but

$$AST_c^t = BI + \text{Max}\begin{Bmatrix} I_1^t + F_1 + F_2 + F_3 + \left(G_a^t + N_a^t\right) \\ D_p \\ D_{ca} + U_{ca} \\ M_a^t \end{Bmatrix}$$

$$+ \beta_2 O^t + \text{Max}\begin{Bmatrix} G_c^t + N_c^t \\ U_p \\ D_{cc} + U_{cc} \\ M_c^t \end{Bmatrix} + \beta_4 DI + BO \qquad \text{(C.4)}$$

We represent the component times of the general-servicing and nitrogen-servicing operations as

$$G_a^t + N_a^t = \text{Max}\begin{Bmatrix} \text{Min}\begin{Bmatrix} D_p - \left(I_1^t + F_1 + F_2 + F_3\right) \\ G^t + \beta_1 N^t \end{Bmatrix} \\ 0 \end{Bmatrix} \qquad \text{(C.4.1)}$$

$$G_b^t + N_b^t = 0 \qquad \text{(C.4.2)}$$

and

$$G_c^t + N_c^t = \left(G^t + \beta_1 N^t\right) - \left(G_a^t + N_a^t\right) - \left(G_b^t + N_b^t\right) \qquad \text{(C.4.3)}$$

We represent the component times of the repair operation as

$$M_a^t = \text{Min}\begin{Bmatrix} \text{Max}\begin{Bmatrix} I_1^t + F_1 + F_2 + F_3 + \left(G_a^t + N_a^t\right) \\ D_p \end{Bmatrix} \\ \beta_3 M^t \end{Bmatrix} \qquad \text{(C.4.4)}$$

$$M_b^t = 0 \qquad \text{(C.4.5)}$$

and

$$M_c^t = \beta_3 M^t - M_a^t - M_b^t \qquad \text{(C.4.6)}$$

We represent the component times of the cargo–off-loading operations as

$$D_{ca} = \text{Min}\begin{cases} \text{Max}\begin{cases} I_1^t + F_1 + F_2 + F_3 + \left(G_a^t + N_a^t\right) \\ D_p \end{cases} \\ D_c \end{cases} \tag{C.4.7}$$

$$D_{cb} = 0 \tag{C.4.8}$$

and

$$D_{cc} = D_c - D_{ca} - D_{cb} \tag{C.4.9}$$

And we represent the component times of the cargo–on-loading operations as

$$U_{ca} = \text{Min}\begin{cases} \text{Max}\left\{\begin{matrix} I_1^t + F_1 + F_2 + F_3 + \left(G_a^t + N_a^t\right) \\ D_p \end{matrix}\right\} - D_{ca} \\ U_c \end{cases} \tag{C.4.10}$$

$$U_{cb} = 0 \tag{C.4.11}$$

and

$$U_{cc} = U_c - U_{ca} - U_{cb} \tag{C.4.12}$$

SERVICING RESOURCES AND THEIR CAPACITIES

The categories of resources considered include parking, servicing teams, and Aerospace Ground Equipment; a complete listing appears in Table 2.3. We calculate the time required of each resource in servicing one mission aircraft by applying standard factors for each ground operation:

$$S_k = \sum_{j=1}^{16} T_{k,j,i} \tag{C.5}$$

where k represents the servicing resource, j indexes over the ground-servicing operations, and i indicates the type of aircraft assigned to the mission.

FUELING EQUATIONS

The equations describing fueling operations and fueling-resource-use times can be divided into three blocks: those concerning hydrant fueling, those concerning truck fueling, and those concerning bulk fuel storage, resupply, and the aggregate fueling capacity of the airfield.

We first discuss each case as if there were only one parking ramp at the airfield, and as if that ramp had only one form of fueling. Then we generalize to many ramps and to dual forms of fueling.

HYDRANT-FUELING EQUATIONS

Hydrant fueling involves moving a hydrant-service vehicle (HSV) to the aircraft; attaching the HSV to the aircraft and the hydrant system, and performing several safety checks; transferring fuel through the hydrant and HSV and into the aircraft; and disconnecting and securing the HSV and hydrant.[1]

Service Times of Hydrant-Fueling Resources

The equations for hydrant fueling are straightforward. We define the service time required of the HSVs for each aircraft being fueled $(S^{F}_{h,\ HSV})$, the service time required of the hydrants $(S^{F}_{h,\ hydrants})$, and the aircraft time required for fueling $\left(F_{2,\ h}\right)$, as

$$S^{F}_{h,\ HSV} = T^{F}_{h,\ drive} + T^{F}_{h,\ hookup} + T^{F}_{h,\ transfer} + T^{F}_{h,\ unhook} \tag{D.1}$$

$$S^{F}_{h,\ hydrants} = T^{F}_{h,\ transfer} \tag{D.2}$$

$$F_{2,\ h} = T^{F}_{h,\ hookup} + T^{F}_{h,\ transfer} + T^{F}_{h,\ unhook} \tag{D.3}$$

where the fuel-transfer time is

[1]The setup of the aircraft for fueling and the securing of the aircraft after fueling are discussed in Chapter Three. Those times are separate from the times discussed in this appendix.

$$T^{F}_{h,\ transfer} = \text{fuel required per aircraft} \Big/ X^{F}_{h,\ transfer\ rate} \tag{D.4}$$

and the fuel-transfer rate is limited by the lowest-performing element of the system:

$$X^{F}_{h,\ transfer\ rate} = \text{Min}\begin{cases}\text{(hydrant pumping rate)}\\ \text{(HSV flow rate)}\\ \text{(aircraft receiving rate)}\end{cases} \tag{D.5}$$

Capacities of Hydrant-Fueling Resources

We can then express the capacities of the resources as

$$C^{F}_{h,\ HSVs} = R^{F}_{h,\ HSVs} * A^{F}_{h,\ HSVs} \Big/ S^{F}_{h,\ HSVs} \tag{D.6}$$

$$C^{F}_{h,\ hydrants} = R^{F}_{h,\ hydrants} * A^{F}_{h,\ hydrants} \Big/ S^{F}_{h,\ hydrants} \tag{D.7}$$

And the fueling capacity of the airfield (assuming, for the moment, that this is the only ramp at the airfield and that truck fueling is not practicable) becomes

$$C^{F}_{h} = \text{Min}\begin{cases}C^{F}_{h,\ HSVs}\\ C^{F}_{h,\ hydrants}\end{cases} \tag{D.8}$$

TRUCK-FUELING EQUATIONS

The equations for truck fueling are more complex, because, as noted in Chapter Four: "Fuel trucks. . . involve much stopping and starting. Trucks have much smaller fuel capacities than hydrants, and when one truck has transferred its load, it must move away from the aircraft to make room for the next full truck. If too few trucks are available, these brief interruptions can turn into long delays while the trucks cycle back to the fill-stand area to replenish their tanks." On the other hand, several trucks may transfer fuel into a single aircraft simultaneously.

Service Times of Truck-Fueling Resources

To describe the service times for truck fueling, we first define several intermediate variables. First, we define the number of trucks that can effectively simultaneously transfer fuel into the specific mission-type aircraft:[2]

---

[2]In this and several of the following equations, Int stands for the "take the integer portion of" function.

$$X^{F}_{t,\ \text{at once}} = \text{Min}\begin{cases} \text{number of SPRs} \\ \text{Int}\left(\dfrac{\text{aircraft receive rate } -1}{\text{truck transfer rate}}\right)+1 \end{cases} \tag{D.9}$$

Then we define the effective rate at which those trucks can transfer fuel into that aircraft,

$$X^{F}_{t,\ \text{transfer rate}} = \text{Min}\begin{cases} (X^{F}_{t,\ \text{at once}} * \text{truck transfer rate}) \\ (\text{aircraft receive rate}) \end{cases} \tag{D.10}$$

And we define the number of truckloads of fuel that each aircraft will need,

$$X^{F}_{t,\ \text{loads}} = \text{Int}\left(\frac{\text{fuel rqred per aircraft} - 1}{\text{capacity of truck}}\right)+1 \tag{D.11}$$

and the time it takes to transfer each (every) truckload of fuel,

$$T^{F}_{t,\ \text{transfer}} = \frac{\text{capacity of truck}}{\text{truck transfer rate}} \tag{D.12}$$

With these definitions, we can express the servicing time of the trucks and crews for each aircraft fueled as

$$S^{F}_{t,\ \text{trucks}} = \left[\begin{pmatrix} T^{F}_{t,\ \text{drive}} + T^{F}_{t,\ \text{hookup}} + T^{F}_{t,\ \text{transfer}} \\ + T^{F}_{t,\ \text{unhook}} + T^{F}_{t,\ \text{drive}} + T^{F}_{t,\ \text{refill}} \end{pmatrix} * X^{F}_{t,\ \text{loads}}\right] + T^{F}_{t,\ \text{secure}} \tag{D.13}$$

Note that these service times are the same whether one truck and crew or several trucks and crews actually service each aircraft. Each truck used on each aircraft must be driven to the aircraft, hooked up, have its fuel transferred, be unhooked, and then be driven back to the fill stand and be refilled.

Finally, fill-stand capacity depends on the use time of each fill stand for each aircraft load of fuel. That is,

$$S^{F}_{\text{fill stands}} = \frac{X^{F}_{t,\ \text{loads}} * \text{capacity of truck}}{\text{Min}\begin{cases} (\text{fill-stand transfer rate}) \\ (\text{truck receive rate}) \end{cases}} \tag{D.14}$$

Capacity of Truck-Fueling Resources

We express the capacity of the trucks as

$$C^{F}_{trucks} = R^{F}_{trucks} * A^{F}_{trucks} / S^{F}_{trucks} \quad \text{(D.15)}$$

And we express the capacity of the fill stands as

$$C^{F}_{fill\ stands} = R^{F}_{fill\ stands} * A^{F}_{fill\ stands} / S^{F}_{fill\ stands} \quad \text{(D.16)}$$

where $R^{F}_{fill\ stands}$ counts the number of outlets at each fill stand, as well as the total number of fill stands.

After those service times have been estimated, we can estimate the maximum number of aircraft that can be serviced in a day at a fuel-parking area with truck fueling only. Similar to the hydrant-fueling case, we express this number as

$$C^{F}_{t} = \text{Min}\begin{cases} C^{F}_{t,\ trucks} \\ C^{F}_{t,\ fill\ stands} \end{cases} \quad \text{(D.17)}$$

Aircraft Time Needed for Fueling

Note that, although the truck-service time per aircraft does not depend on the number of trucks servicing each aircraft, the aircraft-related time usually does—and significantly. If not enough trucks are available, long delays can occur while the trucks cycle back to the fill-stand area to replenish their tanks.

If only one truck is available per aircraft, then the truck time and the aircraft time will be the same. But if more than one truck is available, one can be traveling while the other is transferring fuel, or both can be transferring fuel at the same time. Again, we need several intermediate variables.

First, our rough estimate of the number of trucks that will be available to work on each aircraft,

$$X^{F}_{t,\ avail} = \text{Max}\begin{cases} \dfrac{\text{trucks at airfield} * \text{truck min per day}}{\text{parking min per day}} \\ 1 \end{cases} \quad \text{(D.18)}$$

And, to save space below, we define the time each truck spends "at" the aircraft as

$$T^{F}_{truck\ at\ a/c} = T^{F}_{t,\ hookup} + T^{F}_{t,\ transfer} * T^{F}_{t,\ unhook} \quad \text{(D.19)}$$

Then, we can express our general equation for the time each aircraft being refueled from trucks must spend in fueling—including waiting time as well as active time—as

$$
\begin{aligned}
F_{2,\,t} = {} & T^{\mathrm{F}}_{\mathrm{t,\ drive}} \\
& + \mathrm{Int}\left[\frac{X^{\mathrm{F}}_{\mathrm{t,\ loads}} + \mathrm{Min}\begin{pmatrix} X^{\mathrm{F}}_{\mathrm{t,\ at\ once}} \\ X^{\mathrm{F}}_{\mathrm{t,\ avail}} \end{pmatrix} - 1}{\mathrm{Min}\begin{pmatrix} X^{\mathrm{F}}_{\mathrm{t,\ at\ once}} \\ X^{\mathrm{F}}_{\mathrm{t,\ avail}} \end{pmatrix}} * T^{\mathrm{F}}_{\mathrm{t,\ truck\ at\ a/c}} \right] \\
& + T^{\mathrm{F}}_{\mathrm{t,\ secure}} \\
& + \mathrm{Max}\begin{cases}
\left[\begin{array}{l}
\left(2 * T^{\mathrm{F}}_{\mathrm{t,\ drive}}\right) + \left(\dfrac{\mathrm{Min}\begin{Bmatrix} X^{\mathrm{F}}_{\mathrm{t,\ at\ once}} \\ X^{\mathrm{F}}_{\mathrm{t,\ avail}} \end{Bmatrix} * T^{\mathrm{F}}_{\mathrm{t,\ refill}}}{\mathrm{Min}\begin{Bmatrix} X^{\mathrm{F}}_{\mathrm{t,\ at\ once}} \\ X^{\mathrm{F}}_{\mathrm{t,\ avail}} \\ X^{\mathrm{F}}_{\mathrm{t,\ refill\ at\ once}} \end{Bmatrix}} \right) \\
- \left\{ T^{\mathrm{F}}_{\mathrm{t,\ truck\ at\ a/c}} \left[\mathrm{Int}\left(\dfrac{X^{\mathrm{F}}_{\mathrm{t,\ avail}} - 1}{\mathrm{Min}\begin{Bmatrix} X^{\mathrm{F}}_{\mathrm{t,\ at\ once}} \\ X^{\mathrm{F}}_{\mathrm{t,\ avail}} \end{Bmatrix}} \right) \right] \right\} \\
* \, \mathrm{Int}\left(\dfrac{X^{\mathrm{F}}_{\mathrm{t,\ loads}} - 1}{X^{\mathrm{F}}_{\mathrm{t,\ avail}}} \right)
\end{array} \right] \\
0
\end{cases}
\end{aligned}
\qquad (D.20)
$$

AGGREGATE FUELING CAPACITY

We have described equations for estimating the fueling capacity of a ramp with hydrant fueling and for estimating the fueling capacity of a ramp with truck fueling. Now we must consider both together: That is, we must consider the case of a ramp with hydrant fueling (at least at some of its parking spots) that can be supplemented by truck fueling if (a) truck-fueling resources are available, and (b) parking space and time for mission aircraft are still available for use by the truck-fueling aircraft after the hydrants are operating at their maximum capacity.

Since the hydrant-fueling aircraft and the truck-fueling aircraft compete for the same parking resource here, we specify a management rule to allocate that resource in the most efficient manner: *When both hydrant fueling and truck fueling are available in a ramp, we will use the system with the lowest aircraft-service time first. Then, if resources remain after the capacity of that type of fueling is reached (that is, if parking or bulk fuel is not the constraining resource), we will apply the remaining fuel resources to the other type of fueling.*

For example, suppose an airfield has two ramps, that each ramp has some hydrant-fueling capability, and that each may also support truck fueling. Suppose further that hydrant fueling is faster than truck fueling in both areas, and that hydrant fueling in area 1 is faster than hydrant fueling in area 2, and that truck fueling in area 2 is faster than truck fueling in area 1. That is,

$$\begin{aligned} F_{2,\,h}^{FPA1} &< F_{2,\,t}^{FPA1} \\ F_{2,\,h}^{FPA2} &< F_{2,\,t}^{FPA2} \\ F_{2,\,h}^{FPA1} &< F_{2,\,h}^{FPA2} \\ F_{2,\,t}^{FPA1} &> F_{2,\,t}^{FPA2} \end{aligned} \tag{D.21}$$

Then, to estimate the capacity of the airfield, we must compare the capacities of all the resources. But each capacity must be computed carefully. We cite four distinct cases.

Case One. Fill stands service both ramps and their service time does not depend on which ramp a truck will be returning to. Hence, the capacity of the fill stands is

$$C_{t,\text{ fill stands}}^{F} = \mathrm{R}_{t,\text{ fill stands}}^{F} * \mathrm{A}_{t,\text{ fill stands}}^{F} \Big/ S_{t,\text{ fill stands}}^{F} \tag{D.22}$$

Case Two. Hydrants are specific to ramps; they are not fungible over ramps. Hence, the hydrant capacity of the two ramps is

$$\begin{aligned} C_{h,\text{ hydrants}}^{F} = &\left(\mathrm{R}_{h,\text{ hydrants}}^{F,\text{ FPA1}} * \mathrm{A}_{h,\text{ hydrants}}^{F,\text{ FPA1}} \Big/ S_{h,\text{ hydrants}}^{F,\text{ FPA1}}\right) \\ &+ \left(\mathrm{R}_{h,\text{ hydrants}}^{F,\text{ FPA2}} * \mathrm{A}_{h,\text{ hydrants}}^{F,\text{ FPA2}} \Big/ S_{h,\text{ hydrants}}^{F,\text{ FPA2}}\right) \end{aligned} \tag{D.23}$$

Case Three. Fuel trucks can be used in either ramp, but their productivity varies as the distance from the fill stands varies. HSVs can be used on either ramp, and their productivity varies according to the characteristics of the two hydrant systems. Hence, the capacity of trucks, which are more productive servicing aircraft parked on ramp 2, can be expressed as

$$\begin{aligned} C_{t,\text{ trucks}}^{F} = &\left(\mathrm{R}_{t,\text{ trucks}}^{F} * \mathrm{A}_{t,\text{ trucks}}^{F,\text{ FPA2}} \Big/ S_{t,\text{ trucks}}^{F,\text{ FPA2}}\right) \\ &+ \left[\left(\mathrm{R}_{t,\text{ trucks}}^{F} * \mathrm{A}_{t,\text{ trucks}}^{F}\right) - \left(C_{t,\text{ trucks}}^{F,\text{ FPA2}} * S_{t,\text{ trucks}}^{F,\text{ FPA2}}\right)\right] \Big/ S_{t,\text{ trucks}}^{F,\text{ FPA1}} \end{aligned} \tag{D.24}$$

and the capacity of HSVs, which are more productive servicing aircraft parked on ramp 1, can be expressed as

$$C^{F}_{h,\,HSVs} = \left(R^{F}_{h,\,HSVs} * A^{F,\,FPA1}_{h,\,HSVs} \Big/ S^{F,\,FPA1}_{h,\,HSVs}\right) + \left[\left(R^{F}_{h,\,HSVs} * A^{F}_{h,\,HSVs}\right) - \left(C^{F,\,FPA1}_{h,\,HSVs} * S^{F,\,FPA1}_{h,\,HSVs}\right)\right] \Big/ S^{F,\,FPA2}_{h,\,HSVs} \tag{D.25}$$

These are direct implementations of Equation B.12.

Case Four. Parking is available in both ramps, and it is used for both hydrant and truck fueling. So we express its capacity as

$$C^{P} = \left\{ \begin{array}{l} \left(R^{P,\,FPA1} * A^{P,\,FPA1}_{h} \Big/ S^{P,\,FPA1}_{h}\right) \\ \quad + \left[\left(R^{P,\,FPA1} * A^{P,\,FPA1}\right) - \left(C^{P,\,FPA1}_{h} * S^{P,\,FPA1}_{h}\right)\right] \Big/ S^{P,\,FPA1}_{t} \end{array} \right\} + \left\{ \begin{array}{l} \left(R^{P,\,FPA2} * A^{P,\,FPA2}_{h} \Big/ S^{P,\,FPA2}_{h}\right) \\ \quad + \left[\left(R^{P,\,FPA2} * A^{P,\,FPA2}\right) - \left(C^{P,\,FPA2}_{h} * S^{P,\,FPA2}_{h}\right)\right] \Big/ S^{P,\,FPA2}_{t} \end{array} \right\} \tag{D.26}$$

Fuel Storage and Resupply

We need to add one more consideration before we turn away from fueling. Whether it is done by hydrant or truck, fueling requires a sustaining supply of fuel. So we need to include considerations of fuel storage and resupply. When using a hydrant system, we express the fuel-supply constraint on airfield capacity in aircraft per day,

$$C^{F}_{bulk} = \mathrm{Min}\left\{ \begin{array}{l} \dfrac{(\text{storage capacity} - \text{safety level})}{\text{resupply interval}} \Big/ \left(\text{fuel rqred per aircraft}\right) \\[2ex] \left(\dfrac{\text{resupply qty}}{\text{resupply interval}}\right) \Big/ \left(\text{fuel rqred per aircraft}\right) \\[2ex] \text{bulk pumping capacity per day} \,/\, \left(\text{fuel rqred per aircraft}\right) \end{array} \right. \tag{D.27}$$

When the airfield contains several ramps, they share the fuel supply.

LOADING EQUATIONS

As noted in Chapter Five, we allow for up to three configurations of aircraft: Option A representing maximum cargo with incidental passengers; Option *C* representing maximum passengers with incidental cargo; and Option B representing a feasible intermediate configuration. Estimates of aircraft ground time associated with Option A include time for cargo operations, but assume that the (limited number of) passenger operations occur simultaneously and are completed within the cargo times. Estimates of aircraft ground time associated with Option *C* include time for passenger operations (including the handling of the passengers' personal gear), but assume that the (limited number of) cargo operations can be handled simultaneously and are completed within the passenger times. Estimates of aircraft ground time associated with Option B include times for sequential cargo and passenger operations.

For each mission to be analyzed, the user specifies the type of aircraft, its configuration, the split of space in the cargo bay between nonpalletized and palletized cargo, and the quantities of pallets, passengers, and nonpalletized cargo to be off-loaded and on-loaded at the airfield. We model three types of nonpalletized cargo, but allow only one of these types to be handled per off-load and on-load.

We discuss palletized cargoes first, then passengers, and then the nonpalletized cargoes.

PALLETIZED CARGO

As discussed in the main text, the handling of palletized cargo involves moving a pallet-transporting vehicle to the aircraft; transferring the pallets to or from the aircraft; returning the vehicle to the loading terminal; and then on-loading or off-loading the vehicle at the terminal.

When one transporter has transferred its load, it must move away from the aircraft to make room for the next transporter. If not enough transporters are available, these brief interruptions can turn into long delays while the transporters cycle back to the terminal. We assume that only one transporter may transfer pallets to or from an aircraft at once.

Service Times of Pallet-Handling Resources

To describe the service times for truck fueling, we first define several intermediate variables. First, we define the number of transporter loads that each aircraft will need for the off-load,

$$X^{L}_{c,\text{ loads, down}} = \text{Int}\left(\frac{\text{pallets to be off-loaded} - 1}{\text{capacity of transporter}}\right) + 1 \tag{E.1}$$

and for the on-load,

$$X^{L}_{c,\text{ loads, up}} = \text{Int}\left(\frac{\text{pallets to be on-loaded} - 1}{\text{capacity of transporter}}\right) + 1 \tag{E.2}$$

Then, we define the time it takes to transfer pallets from and to the transporter at the terminal for the off-load,

$$T^{L}_{c,\text{ term, d}} = \left(\begin{array}{c}\text{minutes to off-load 1 pallet at terminal} \\ * \text{ capacity of transporter}\end{array}\right) \tag{E.3}$$

and for the on-load,

$$T^{L}_{c,\text{ term, u}} = \left(\begin{array}{c}\text{minutes to on-load 1 pallet at terminal} \\ * \text{ capacity of transporter}\end{array}\right) \tag{E.4}$$

Finally, we define the time it takes to transfer pallets from and to the transporter at the aircraft,

$$T^{L}_{c,\text{ a/c, d}} = \left(\begin{array}{c}\text{minutes to off-load 1 pallet from the a/c} \\ * \text{ capacity of transporter}\end{array}\right) \tag{E.5}$$

$$T^{L}_{c,\text{ a/c, u}} = \left(\begin{array}{c}\text{minutes to on-load 1 pallet into the a/c} \\ * \text{ capacity of transporter}\end{array}\right) \tag{E.6}$$

With these definitions, we can express the servicing time of the transporters for each aircraft serviced as

$$S^{L}_{c,\text{ transporter, down}} = \left(\begin{array}{c}T^{L}_{c,\text{ drive}} + T^{L}_{c,\text{ term, down}} \\ + T^{L}_{c,\text{ drive}} + T^{L}_{c,\text{ a/c, down}}\end{array}\right) * X^{L}_{c,\text{ loads, down}} \tag{E.7}$$

for the off-load, and

$$S^{L}_{c,\ transporter,\ up} = \begin{pmatrix} T^{L}_{c,\ drive} + T^{L}_{c,\ term,\ up} \\ + T^{L}_{c,\ drive} + T^{L}_{c,\ a/c,\ up} \end{pmatrix} * X^{L}_{c,\ loads,\ up} \qquad (E.8)$$

for the on-load. This means that the total service time can be expressed as

$$S^{L}_{c,\ transporter} = S^{L}_{c,\ transporter,\ down} + S^{L}_{c,\ transporter,\ up} \qquad (E.9)$$

Note that these service times are the same whether one transporter or several transporters actually service each aircraft. Each transporter used on each aircraft must be driven to the aircraft, positioned, have its pallets transferred, be unpositioned, and then drive back to the terminal.

Aircraft Time Needed for Pallet Handling

Note that although the transporter-service time per aircraft does not depend on the number of transporters servicing each aircraft, the aircraft-related time usually does—and significantly. If not enough transporters are available, long delays can occur while the transporters cycle back to the terminal area.

If only one transporter is available per aircraft, then the transporter time and the aircraft time will be the same. But if more than one transporter is available, one of them can be traveling while the other is loading, or both can be loading at the same time. Again, we need several intermediate variables.

First, we make a rough estimate of the number of transporters that will be available to work on each aircraft:

$$X^{L}_{c,\ avail} = \mathrm{Max}\begin{cases} \dfrac{\text{transporters at airfield} * \text{transporter minutes per day}}{\text{parking minutes per day}} \\ 1 \end{cases} \qquad (E.10)$$

And, to save space below, we define the *cycle time for each transporter*, the time it spends away from the aircraft, as

$$T^{L}_{c,\ cycle,\ down} = T^{L}_{c,\ drive} + T^{L}_{c,\ term,\ down} * T^{L}_{c,\ drive} \qquad (E.11)$$

for the off-load, and

$$T^{L}_{c,\ \text{cycle, up}} = T^{L}_{c,\ \text{drive}} + T^{L}_{c,\ \text{term, up}} * T^{L}_{c,\ \text{drive}} \tag{E.12}$$

for the on-load.

Then, we can express the pallet-loading delays as

$$T^{L}_{c,\ \text{delay, down}} = \text{Max}\begin{cases} \left[\left\{T^{L}_{c,\ \text{cycle, down}} - \left[T^{L}_{c,\ \text{a/c, down}} * \left(X^{L}_{c,\ \text{avail}} - 1\right)\right]\right\} * \text{Int}\left(\dfrac{X^{L}_{c,\ \text{loads, down}} - 1}{X^{L}_{c,\ \text{avail}}}\right)\right] \\ 0 \end{cases} \tag{E.13}$$

for the off-load, and

$$T^{L}_{c,\ \text{delay, up}} = \text{Max}\begin{cases} \left[\left\{T^{L}_{c,\ \text{cycle, up}} - \left[T^{L}_{c,\ \text{a/c, up}} * \left(X^{L}_{c,\ \text{avail}} - 1\right)\right]\right\} * \text{Int}\left(\dfrac{X^{L}_{c,\ \text{loads, up}} - 1}{X^{L}_{c,\ \text{avail}}}\right)\right] \\ 0 \end{cases} \tag{E.14}$$

for the on-load.

Then, we can express the time each aircraft spends having pallets on-loaded or off-loaded—including waiting time as well as active time—as

$$D_{c,\ p} = \left(T^{L}_{c,\ \text{a/c, down}} * X^{L}_{c,\ \text{loads, down}}\right) + T^{L}_{c,\ \text{delay, down}} \tag{E.15}$$

for the off-load, and

$$U_{c,\ p} = \left(T^{L}_{c,\ \text{a/c, up}} * X^{L}_{c,\ \text{loads, up}}\right) + T^{L}_{c,\ \text{delay, up}} \tag{E.16}$$

for the on-load.

Capacity of Pallet-Loading Resources

We express the capacity of the transporters as

$$C^{L}_{c,\ \text{transporters}} = \frac{R^{L}_{c,\ \text{transporters}} * A^{L}_{c,\ \text{transporters}}}{S^{L}_{c,\ \text{transporters}}} \tag{E.17}$$

Service time for the wide-body elevator loaders (WBELs) helping with the on- or off-loading of pallets, is equivalent to the total aircraft pallet service time. That is,

$$S^{L}_{c,\ \mathrm{WBELs}} = D_{c,p} + U_{c,p} \tag{E.18}$$

So the capacity of the WBELs is

$$C^{L}_{\mathrm{WBELs}} = \frac{R^{L}_{\mathrm{WBELs}} * A^{L}_{\mathrm{WBELs}}}{S^{L}_{c,\ \mathrm{WBELs}}} \tag{E.19}$$

PASSENGERS

To describe the service times for passenger on-loading and off-loading, we first define several intermediate variables. First, we define the number of busloads that each aircraft will need,

$$X^{L}_{b,\ \mathrm{loads,\ down}} = \mathrm{Int}\left(\frac{\text{pax to be off-loaded} - 1}{\text{capacity of airfield bus}}\right) + 1 \tag{E.20}$$

for the off-load, and

$$X^{L}_{b,\ \mathrm{loads,\ up}} = \mathrm{Int}\left(\frac{\text{pax to be on-loaded} - 1}{\text{capacity of airfield bus}}\right) + 1 \tag{E.21}$$

for the on-load.

Then we define the time it takes to transfer pallets from and to the transporter at the terminal,

$$T^{L}_{b,\ \mathrm{term,\ d}} = \left[\begin{array}{c}\text{minutes to off-load std bus at the terminal} \\ * \left(\dfrac{\text{capacity of airfield bus}}{\text{capacity of std bus}}\right)\end{array}\right] \tag{E.22}$$

for the off-load, and

$$T^{L}_{b,\ \mathrm{term,\ u}} = \left[\begin{array}{c}\text{minutes to on-load std bus at the terminal} \\ * \left(\dfrac{\text{capacity of airfield bus}}{\text{capacity of std bus}}\right)\end{array}\right] \tag{E.23}$$

for the on-load.

Finally, we define the time it takes to transfer pallets from and to the transporter at the aircraft,

$$T^{L}_{b,\ \mathrm{a/c,\ d}} = \left[\begin{array}{c}\text{minutes to off-load std bus at the a/c} \\ * \left(\dfrac{\text{capacity of airfield bus}}{\text{capacity of std bus}}\right)\end{array}\right] \tag{E.24}$$

$$T^{L}_{b,\ a/c,\ u} = \left[\begin{array}{c} \text{minutes to on-load std bus at the a/c} \\ * \left(\dfrac{\text{capacity of airfield bus}}{\text{capacity of std bus}} \right) \end{array} \right] \tag{E.25}$$

With these definitions, we can express the servicing time of the transporters for each aircraft serviced as

$$S^{L}_{b,\ bus,\ down} = \left(\begin{array}{c} T^{L}_{b,\ drive} + T^{L}_{b,\ term,\ down} \\ + T^{L}_{b,\ drive} + T^{L}_{b,\ a/c,\ down} \end{array} \right) * X^{L}_{b,\ loads,\ down} \tag{E.26}$$

for the off-load, and

$$S^{L}_{b,\ bus,\ up} = \left(\begin{array}{c} T^{L}_{b,\ drive} + T^{L}_{b,\ term,\ up} \\ + T^{L}_{b,\ drive} + T^{L}_{b,\ a/c,\ up} \end{array} \right) * X^{L}_{b,\ loads,\ up} \tag{E.27}$$

for the on-load. This means that the total service time can be expressed as

$$S^{L}_{b,\ bus} = S^{L}_{b,\ bus,\ down} + S^{L}_{b,\ bus,\ up} \tag{E.28}$$

Note that these service times are the same whether one bus or several buses actually service each aircraft. Each bus used on each aircraft must be driven to the aircraft, wait while its passengers transfer to the aircraft, and then be driven back to the terminal.

Aircraft Time Needed for Passenger Handling

Note that although the bus-service time per aircraft does not depend on the number of buses servicing each aircraft, the aircraft-related time usually does—and significantly. If not enough buses are available, long delays can occur while the buses cycle back to the terminal area.

If only one bus is available per aircraft, then the bus time and the aircraft time will be the same. But if more than one bus is available, then one of them can be traveling while the other is loading, or both can be loading or traveling at the same time. Again we need several intermediate variables.

First, we make a rough estimate of the number of transporters that will be available to work on each aircraft,

$$X^{L}_{b,\ avail} = \text{Max} \begin{cases} \dfrac{\text{buses at airfield} * \text{bus min per day}}{\text{parking min per day}} \\ 1 \end{cases} \tag{E.29}$$

And, to save space below, we define the cycle time for each transporter, the time it spends away from the aircraft, as

$$T^{L}_{b,\ \text{cycle, down}} = T^{L}_{b,\ \text{drive}} + T^{L}_{b,\ \text{term, down}} * T^{L}_{b,\ \text{drive}} \tag{E.30}$$

for the off-load, and

$$T^{L}_{b,\ \text{cycle, up}} = T^{L}_{b,\ \text{drive}} + T^{L}_{b,\ \text{term, up}} * T^{L}_{b,\ \text{drive}} \tag{E.31}$$

for the on-load.

Then, we can express the passenger-loading delays as

$$T^{L}_{b,\ \text{delay, down}} = \text{Max}\begin{cases} \left[\left\{T^{L}_{b,\ \text{cycle, down}} - \left[T^{L}_{b,\ \text{a/c, down}} * \left(X^{L}_{b,\ \text{avail}} - 1\right)\right]\right\} * \text{Int}\left(\dfrac{X^{L}_{b,\ \text{loads, down}} - 1}{X^{L}_{b,\ \text{avail}}}\right)\right] \\ 0 \end{cases} \tag{E.32}$$

for the off-load, and

$$T^{L}_{b,\ \text{delay, up}} = \text{Max}\begin{cases} \left[\left\{T^{L}_{b,\ \text{cycle, up}} - \left[T^{L}_{b,\ \text{a/c, up}} * \left(X^{L}_{b,\ \text{avail}} - 1\right)\right]\right\} * \text{Int}\left(\dfrac{X^{L}_{b,\ \text{loads, up}} - 1}{X^{L}_{b,\ \text{avail}}}\right)\right] \\ 0 \end{cases} \tag{E.33}$$

for the on-load.

Then, we can express the time each aircraft spends having passengers on-loaded or off-loaded—including waiting time as well as active time—as

$$S^{L}_{b,\ \text{down}} = \left(T^{L}_{b,\ \text{a/c, down}} * X^{L}_{b,\ \text{loads, down}}\right) + T^{L}_{b,\ \text{delay, down}} \tag{E.34}$$

for the off-load, and

$$S^{L}_{b,\ \text{up}} = \left(T^{L}_{b,\ \text{a/c, up}} * X^{L}_{b,\ \text{loads, up}}\right) + T^{L}_{b,\ \text{delay, up}} \tag{E.35}$$

for the on-load.

Capacity of Passenger-Handling Resources

After those service times have been estimated, we can estimate the maximum number of aircraft that can be serviced in a day at a fuel-parking area with truck fueling only. We express this as

$$C^{L}_{\text{buses}} = \frac{R_{\text{bus}} * A^{L}_{\text{bus}}}{S^{L}_{\text{b, bus}}} \tag{E.36}$$

NONPALLETIZED CARGO

In this initial implementation of ACE, we do not model the preparation of nonpalletized cargo (NPC) for airlift or its movement to the aircraft. We expect those activities may be added later.

For specifying the ground time associated with on-loading and/or off-loading NPC from aircraft, we define a set of equations for the second task listed in the right-hand column of Table 5.5. Loading times associated with the nonpalletized cargoes contribute to the aircraft's ground time.

We represent the time required to transfer a full load of nonpalletized cargo from the aircraft and ready it for ground movement as $T^{L}_{\text{n, down, full}}$. Similarly, we represent the time required to transfer a full load of nonpalletized cargo into the aircraft and get it secured as $T^{L}_{\text{n, up, full}}$.

Note that these times are associated with *full* loads of nonpalletized cargoes. We then represent the aircraft times associated with handling partial loads of nonpalletized cargo as

$$D_{\text{c, n}} = T^{L}_{\text{n, down, full}} * \text{Percent to be off-loaded} \tag{E.37}$$

and

$$U_{\text{c,n}} = T^{L}_{\text{n, up, full}} * \text{Percent to be on-loaded} \tag{E.38}$$

AGGREGATE LOADING RESOURCES

The service time for the aggregate loading resource is the sum of the pallet, passenger, and NPC times for off-loading and on-loading:

$$S^{L}_{\text{agg}} = D_{\text{c, p}} + U_{\text{c, p}} + D_{\text{p}} + U_{\text{p}} + D_{\text{c, n}} + U_{\text{c, n}} \tag{E.39}$$

$$C^{L}_{\text{agg}} = R^{L}_{\text{agg}} * A^{L}_{\text{agg}} / S^{L}_{\text{agg}} \tag{E.40}$$

AIRCRAFT LOADING TIMES

Now that we have described most of the components of aircraft loading times, we need only to aggregate them and to add some aircraft setup times where appropriate.

Most aircraft need some relatively short period of time to set up for off-loading and on-loading: Some need different times depending on what type of cargo is being off-loaded or on-loaded, and some need to perform some basic operations before any loading activities can be undertaken. We allow for all these cases by specifying four setup times, any or all of which may be zero for a particular aircraft or mission.

We specify total aircraft times for loading, in sequence, as

$$D_{\mathrm{p}} = S^{\mathrm{L}}_{\mathrm{b,\ down}} + \begin{cases} T^{\mathrm{L}}_{\mathrm{b,\ set\ up}} + T^{\mathrm{L}}_{\mathrm{set\ up}} & \text{if } S^{\mathrm{L}}_{\mathrm{b,\ down}} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{E.41}$$

$$\begin{aligned} D_{\mathrm{c}} = D_{\mathrm{c,\ p}} &+ \begin{cases} T^{\mathrm{L}}_{\mathrm{c,\ p,\ set\ up}} & \text{if } D_{\mathrm{c,\ p}} > 0 \\ 0 & \text{otherwise} \end{cases} \\ &+ D_{\mathrm{c,\ n}} + \begin{cases} T^{\mathrm{L}}_{\mathrm{c,\ n,\ set\ up}} & \text{if } D_{\mathrm{c,\ n}} > 0 \\ 0 & \text{otherwise} \end{cases} \\ &+ \begin{cases} T^{\mathrm{L}}_{\mathrm{set\ up}} \text{ if } \mathrm{D_p} = 0 \text{ and } \begin{cases} \mathrm{D_{c,\ p}} > 0 \\ \text{or} \\ \mathrm{D_{c,\ n}} > 0 \end{cases} \\ 0 \quad \text{otherwise} \end{cases} \end{aligned} \tag{E.42}$$

$$U_{c} = U_{c,\,p} + \begin{cases} T^{L}_{c,\,p,\,\text{set up}} & \text{if } D_{c,\,p} = 0 \text{ and } U_{c,\,p} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$+ \; U_{c,\,n} + \begin{cases} T^{L}_{c,\,n,\,\text{set up}} & \text{if } D_{c,\,n} = 0 \text{ and } U_{c,\,n} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$+ \begin{cases} T^{L}_{\text{set up}} \text{ if } D_{p} = 0 \text{ and } D_{c} = 0 \text{ and} \begin{cases} U_{c,\,p} > 0 \\ \text{or} \\ U_{c,\,n} > 0 \end{cases} \\ 0 \quad \text{otherwise} \end{cases} \tag{E.43}$$

$$U_{p} = S^{L}_{b,\,\text{up}} + \begin{cases} T^{L}_{p,\,\text{set up}} & \text{if } D_{p} = 0 \text{ and } U_{p} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$+ \begin{cases} T^{L}_{\text{set up}} & \text{if } D_{p} = 0 \text{ and } D_{c} = 0 \text{ and } U_{c} = 0 \text{ and } S^{L}_{b,\,\text{up}} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{E.44}$$

TIPS FOR USING ACE

ACE is written in Visual Basic for Applications and runs on a PC or Macintosh with Excel 5 or Excel 95 and a high-resolution monitor. The ACE package consists of 7 Excel workbooks containing 52 worksheets and 16 code modules. The model itself, the part the user runs at one time, comprises 4 workbooks containing 34 worksheets and 13 code modules. The other workbooks contain templates and examples for recording and retaining data from and/or for specific airfields. Table F.1 lists the workbooks and the worksheets and coding modules they comprise. Double clicking on the ACE.XLS workbook icon will cause Excel 5 to activate and all four workbooks to load.

In this appendix, we expand on the information presented in Chapter Six to help the user understand what is going on in the model.

CHANGING PARAMETER VALUES

Figure 6.4 listed the screens (the formatted worksheets) holding the airfield and global parameters and indicated the path to reaching each set of parameters. Appendix G shows the parameter values currently associated with each screen. The user can change those parameter values by simply typing in a new value in place of the current value. Care must be exercised, however, to ensure that the new values are not saved with the worksheets, unless the user desires to make the changes permanent.

SETTING UP MISSIONS

We discussed the basic specification of mission parameters in Chapter Six. But knowing a little more about which dropdowns affect which other dropdowns will increase the user's confidence in specifying items and reduce the chance of unsuspected errors being introduced when mission specifications are altered.

Clicking on the Setup button for any mission initiates the location and consolidation of parameters for the aircraft type, configuration, and ground-servicing profile selected; it also initiates subroutines, setting up initial menus for the dropdowns located in the lower portion of the mission column. Clicking on some of those lower-portion dropdowns then alters some of the menus associated with other dropdowns. Specifically, activating the fuel-quantity dropdown alters the fuel-isolation menu,

Table F.1

The ACE Workbooks, Worksheets, and Modules

Workbooks	Worksheets	Modules
ACE	Welcome	Code
	MCSetUp	SetUps
	Logo	
	Mission	
ACE_CODE		Module 1[a]
		Module 2
		Module 3
		Module 4
		Module 5
		Module 6
		Module 7
		Module 8
		Module 9
ACE_COMP	Outputs	Module 1
	Comps	
	MData	
	PData	
	ROut	
	IOut	
	Custom	
	OpsTimes	
	Tracks	
ACE_DATA	ParameterControl	Code
	Import	
	Export	
	AFControl	
	AFFPAs	
	AFAGRes	
	AFFuelRes	
	AFAPRes	
	AFOAFRes	
	GloControl	
	GACChar	
	GAGTimes	
	GAGE	
	GFuel	
	GACFuelChar	
	GVehFuelChar	
	GFuelTimes	
	GAerialPort	
	GVehAPChar	
	GAPTimes	
	Distributions	
Totals	34	13

[a]Module 1 in the ACE_CODE worksheet lists all of the ACE subroutines and their locations.

and activating the pallets-off and pallets-on dropdowns alters the NPC-off and NPC-on menus. Hence, if the user selects values for the fuel-quantity, pallets-off, pallets-on, or the NPC-type dropdowns and subsequently wishes to change any of those selections, (s)he should first reclick on the Setup button and then work vertically down through the dropdowns.

The best policy is always to reclick the Setup button after any error or change of mind in working the bottom portion of the column. Whenever changes are made to the top portion of a mission column, the Setup button *must* be reclicked and *all* of the dropdowns in the bottom portion must be activated.

EVALUATING MISSIONS

Procedures for evaluating missions under the two modes of analysis—expected value and Monte Carlo—are quite similar, but it may help to discuss them one at a time. However, we illustrate them in the same figure, so that comparisons and contrasts can be made.

Expected-Value Calculations

The left-hand portion of Figure F.1 illustrates the program flow for an expected-value calculation after the user clicks on one of the Eval buttons (recall Figure 6.7). Every time the user initiates an evaluation of mission 1, the subroutines clean up the output workspaces, initialize all of the airfield resources, evaluate the mission (for the number of aircraft specified), and then copy numerous values to the several output screens.

Because the spreadsheets evaluate all six parking areas and their hydrant- and truck-based fueling operations in parallel, it takes the program no longer to evaluate an airfield with six parking areas than to evaluate an airfield with a single parking area. What does take iterations and time is the successive evaluation of parking areas when the best area—the one with the shortest aircraft ground time for the specified mission—cannot handle the required number of aircraft. When that occurs, the program notes the best area and the number of aircraft it can handle and then iterates to identify the next-best area and how many aircraft that one can handle. When fueling is involved, a run can involve up to 12 iterations, because each ramp can support both hydrant- and truck-based fueling. When fueling is not involved, there should be no more than six iterations.[1]

Recall also that, for each of these iterations, there are, in fact, 16 separate sub-iterations of the worksheet, one for each element of Eq. C.1. The final sub-iteration—

[1]The current iteration number is always displayed in cell I285 of the "comps" spreadsheet in the ACE_COMP workbook. So at the end of a run, that cell will indicate the number of iterations that had been required.

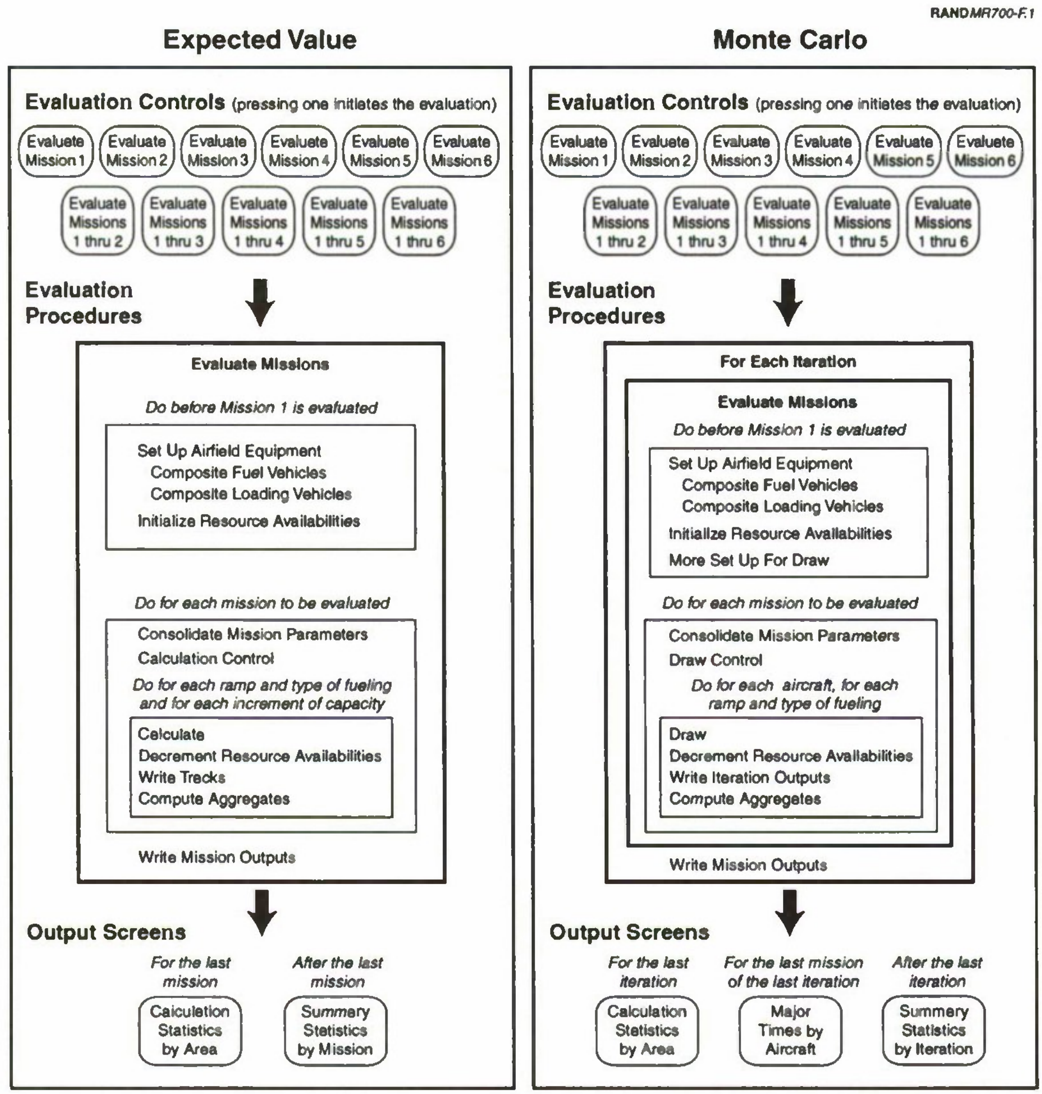


Figure F.1—Flow Diagrams

the one whose values remain on the spreadsheets—is then the one including full values for the nitrogen servicing, oxygen servicing, repair, and de-icing.[2]

Monte Carlo Analysis

The right-hand side of Figure F.1 shows the flow for a Monte Carlo run. Here, the major iteration is over the "mission set," the several missions that will be analyzed together. The user specifies the set by selecting and pressing one Evaluate button

[2]This remains true even when some of those items are excluded from the mission by setting their alpha frequencies to zero (see Screen G.9). The equations are always evaluated with beta values of both ones and zeros (see Eq. C.1).

(just as for an expected-value run), but only after having specified the number of iterations of the mission set to be performed.

The program flow is then much the same as before. The EvaluateMissions subroutine controls the overall flow, calling the other routines as necessary and as many times as is necessary. We noted above that the program performs 16 separate sub-iterations of the worksheet to achieve one expected-value iteration. In Monte Carlo mode, it performs only one—the one using specific draws for each of the probabilistic variables. This means that in the expected-value mode, one mission with 25 aircraft will require 16 calculations of the spreadsheet if all those aircraft can be serviced, fueled, and loaded over the day in the "best" service area and best fueling manner; 32 calculations if those aircraft require two areas or types of fueling; etc. In the Monte Carlo mode, however, that analysis would always require 25 calculations, one for each aircraft, whether or not they use one or six parking areas and zero, one, or two types of fueling. If we iterate that evaluation 100 times, the Monte Carlo analysis will perform 2,500 calculations.

Missions requesting "zero" aircraft always require 16 calculations under the expected-value mode and one under the Monte Carlo mode. This calculation determines the best area and type of fueling and provides estimates of resource-use times, aircraft ground times, and, based on those servicing times, an estimate of the capacity of the entire airfield (that is, all areas and types of fueling).

FILES FOR SPECIFIC AIRFIELDS

In the early versions of ACE, we found it convenient to automatically attach and unattach files containing parameters for specific airfields, so we have added that capability to version 2.

The workbook ACE_DATA.XLS opens whenever ACE does and contains both global and airfield parameters. The subroutines and cells with the other ACE workbooks access only those workbooks for data. So, to run ACE with data from a specific airfield, we simply incorporate that information into an empty (stationary) workbook having worksheets identical to those in the airfield portion of ACE_DATA.XLS, and then read those into that workbook, overwriting the preexisting values.

Similarly, to save airfield information currently in ACE_DATA.XLS, we simply copy it to an empty workbook having worksheets identical to those in ACE_DATA.XLS. Subroutines for these copies are stored in the code module of ACE_DATA.XLS and can be called from its first, ParameterControl, worksheet. See Figures 6.4, F.2, and F.3. As noted at the beginning of this appendix, several sample airfield files, as well as the empty (stationary) workbook, are included with the ACE files.

CUSTOMIZING MISSIONS

As noted in the text, the user can customize the times and/or frequencies of any ground-servicing operation in the model, and, with a little ingenuity, can handle many changes to the scheduling or sequencing of operations, as follows.

To insert new times for ground operations associated with a mission or a set of up to six missions, the user clicks the lowest button in a mission column on the Mission screen/spreadsheet. This brings the "custom" spreadsheets to the screen, and here the user can observe the operation times and frequencies gathered by ACE for the missions just set up and, if (s)he wishes, change any of those times or frequencies.

To analyze an engine-running off-load, for example, the user would simply set the operation times (or frequencies) for the operations to be suspended on that run—probably the through-flight inspection, general servicing, and the nitrogen and oxygen servicing—to zero. If desired, the repair time or frequency could also be set to zero, but that would be less realistic.

Note that these customizations can be made only after the missions have been completely set up on the Mission screen spreadsheet. And note that the customizations for each mission are erased as soon as the Setup button for that mission is reclicked or if the evaluation of the mission set is iterated. Iteration causes a new copy of data

RAND MR700-F.2

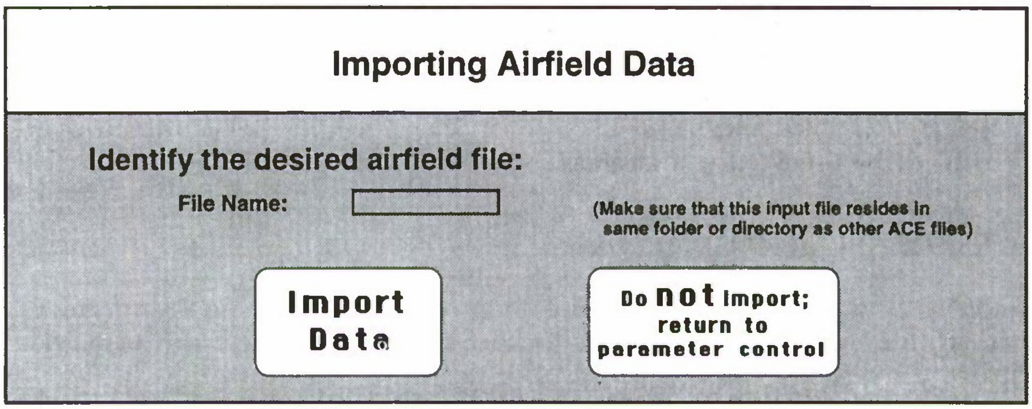


Figure F.2—Screen for Importing Airfield Files

RAND MR700-F.3

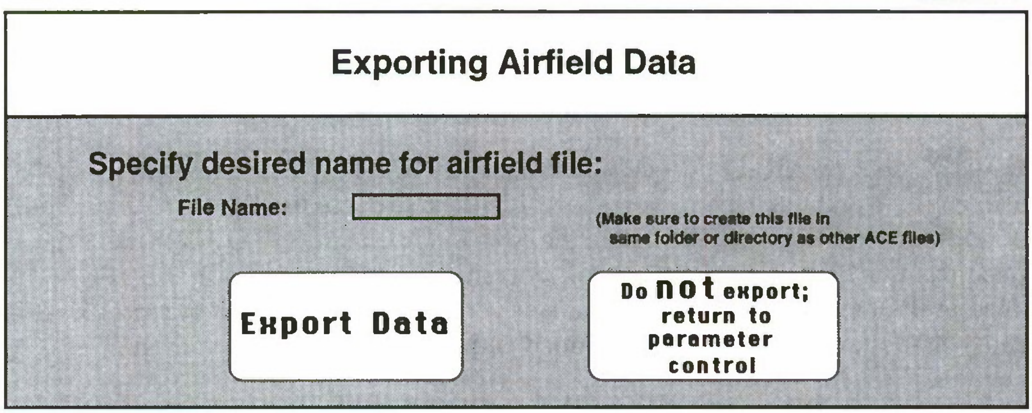


Figure F.3—Screen for Saving Airfield Files

for mission 1 to be reincorporated into the ACE_COMP.XLS spreadsheet, erasing any customizations that may have been entered there. Thus, this type of customization does not work for iterated Monte Carlo runs; those require (at least temporary) changes in global parameters.

TROUBLESHOOTING

In addition to the Output screens, several other screen worksheets in the ACE_COMP workbook can be very helpful when any of the outputs seem questionable.

- The MData worksheet contains the specific data used in each evaluation.
- The Comps worksheet, as noted, is where most of the actual computations occur; hence, after the run, it contains values for the final iteration of the final evaluation of the run.
- The OpsTimes spreadsheet illustrates the sequenced operation-time values (based on Eqs. C.2, C.3, and C.4) for the final evaluation. Consulting this display, the user can see just which times, if any, are being masked by others (at least in the final iteration of the final evaluation).
- Finally, the Tracks spreadsheet contains a complete record of the resource-availability times for every evaluation in the final mission of an expected-value run.

Appendix G

SCREENS AND DATA

This appendix presents screen-captures of worksheets in the ACE_DATA workbook. These worksheets contain all of the global and airfield parameters used in ACE calculations. The initial screen for this workbook was shown as Figure 6.3. We present the airfield parameters first, then the global parameters.

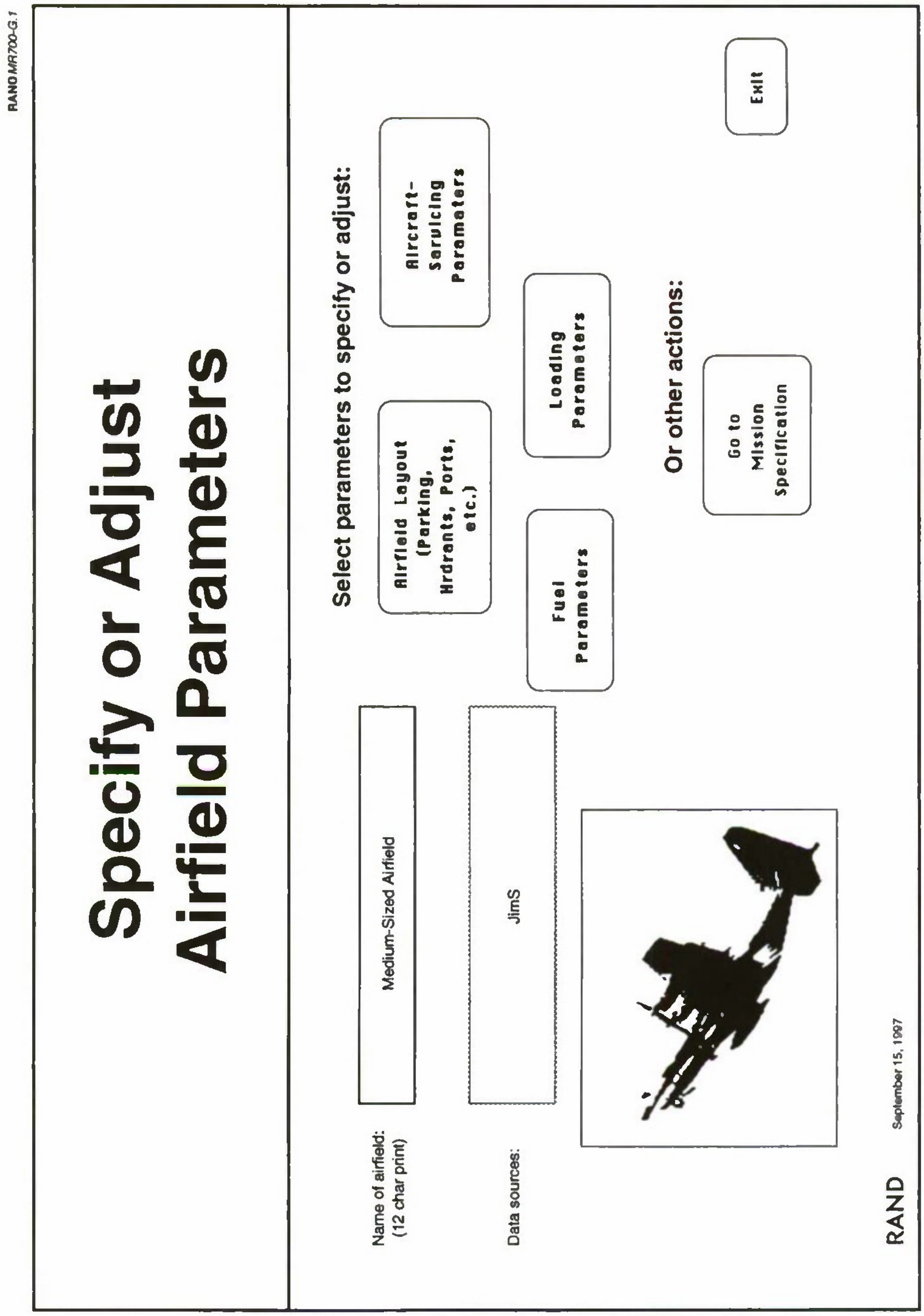


Figure G.1—Airfield-Parameter Control

RANDMR700-G.2

Parking and Hydrant-Fueling Parameters

	FPA #1	FPA #2	FPA #3	FPA #4	FPA #5	FPA #6
Designation	A	B	C			
Parking service time (hrs/day)	24	24	24	0	0	0
Capacity						
C-130	3	8	5	0	0	0
C-141	3	8	5	0	0	0
C-5	0	5	0	0	0	0
C-17	3	8	5	0	0	0
KC-10	0	5	0	0	0	0
KC-135	3	8	5	0	0	0
747	0	5	0	0	0	0
Cxx	0	0	0	0	0	0
Cyy	0	0	0	0	0	0
Hydrant fueling						
Number of aircraft can fuel at once	0	5	0	0	0	0
Fueling rate per aircraft (gal/min)	0	500	0	0	0	0
Availability (hr/day)	0	24	0	0	0	0
Distance (ft) to fuel fill stands	9,000	4,500	1,500	0	0	0
Distance (ft) to cargo terminal/storage	500	2,000	8,000	0	0	0
Distance (ft) to pax terminal/holding	8,000	1,000	5,000	0	0	0

Figure G.2—Parking-Area Parameters

RANDMR700-G.3

Aircraft-Servicing Resources

Aerospace-Ground Equipment

	Quantity	Availability (hrs/day)
Ground-power unit	5	20
Stand, low	20	24
Stand, medium	20	24
Stand, high	20	24
Oil cart	20	23
Gaseous-oxygen cart	20	22
Liquid-oxygen cart	20	22
Liquid-nitrogen cart	20	22
Liquid-nitrogen truck	20	20
De-icer	10	18
Calivar	5	24

Aircraft Maintenance Crews

Aircraft Servicing	Number of Crews *	Availability (hrs/day)
C-130	5	24
C-141	5	24
C-5	5	24
C-17	5	24
KC-10	5	24
KC-135	5	24
747	5	24
Cxx	0	24
Cyy	0	24

*We assume one crew can work one aircraft at a time

Aggregate Aircraft-Servicing Resources

Number of aircraft can work at once	5
Hours per day they can do so	24
Average service time (min)	computed

Figure G.3—Servicing-Resource Parameters

RANDMR700-G.4

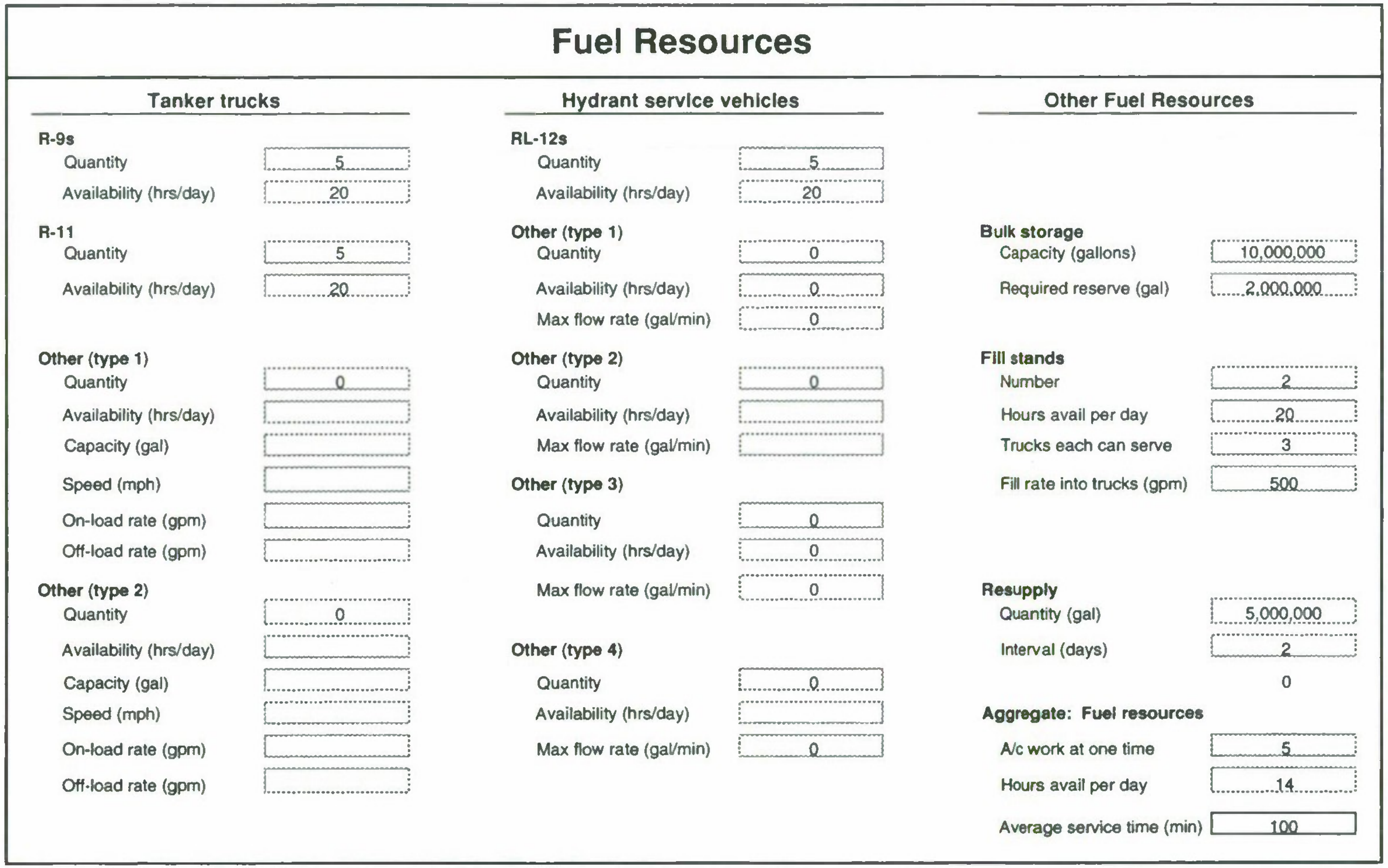


Figure G.4—Fuel-Resource Parameters

RAND MR700-G.4A

Airfield Fuel-Related Composite Variables		
Item	Dimension	Value
Composite HSV		
quantity of composite HSV	count	5
availability of composite HSV	minutes per day	1,200
flow rate of composite HSV	gallons per minute	750
Composite tanker truck		
quantity of composite truck	count	10
availability of composite truck	minutes per day	1,200
capacity of composite truck	gallons	5,200
speed of composite truck	feet per minute	440
transfer rate of composite truck	gallons per minute	550
receive rate of composite truck	gallons per minute	600

Figure G.4A—Fuel-Resource Compositing Workspace

RAND MR700-G.5

Loading Resources

Buses

Other (type 1)	
Quantity	5
Availability (hrs/day)	20
Cap (people with gear)	25
Speed (mph)	35
On-load time (min)	
Off-load time (min)	
Other (type 2)	
Quantity	0
Availability (hrs/day)	0
Cap (people with gear)	0
Speed (mph)	0
On-load time (min)	
Off-load time (min)	
Other (type 3)	
Quantity	0
Availability (hrs/day)	0
Cap (people with gear)	0
Speed (mph)	0
On-load time (min)	
Off-load time (min)	

Material-Handling Equipment

k-Loaders and other transporters	Quantity (count)	Availability (hr per day)
25k	0	0
40k	20	2.35
60k	0	0
Forklifts	0	0

Wide-Body Elevator Loaders	Quantity (count)	Availability (hr per day)
Cochran	20	1.92
Wilson	0	0
TA-40	0	0

WBELs, Others	Type 1	Type 2
Quantity	0	0
Availability (hrs/day)	0	0
Capacity (pallets)	0	0
Speed (mph)	0	0

Aggregate Loading Resources

A/c work at one time	5
Hours avail per day	24
Avg service time (min)	100

Figure G.5—Loading-Resource Parameters

RAND MR700-G.5A

Airfield Loading-Related Composite Variables

Item	Dimension	Value
Buses		
quantity of composite bus	count	5
availability of composite bus	minutes per day	1,200
capacity of composite bus	persons	25
speed of composite bus	feet per minute	3,080
k-Loaders		
quantity of composite k-loader	count	20
availability of composite k-loader	minutes per day	141
capacity of composite k-loader	pallets	5
speed of composite k-loader	feet per minute	1,320
WBELs		
quantity of composite WBEL	count	20
availability of composite WBEL	minutes per day	115
capacity of composite WBEL	pallets	2
speed of composite WBEL	feet per minute	220

Figure G.5A—Loading-Resource Compositing Workspace

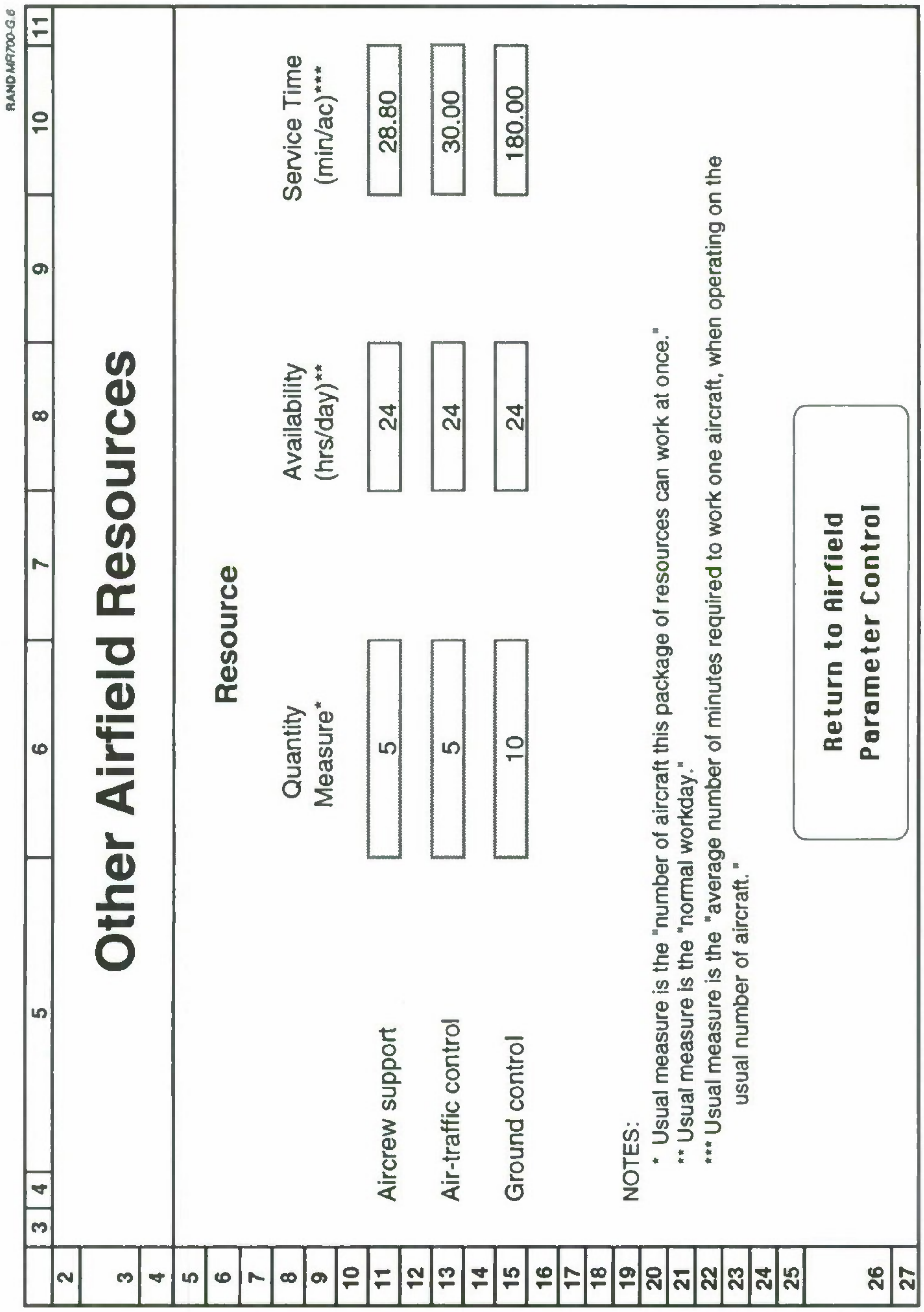


Figure G.6—Other-Resource Parameters

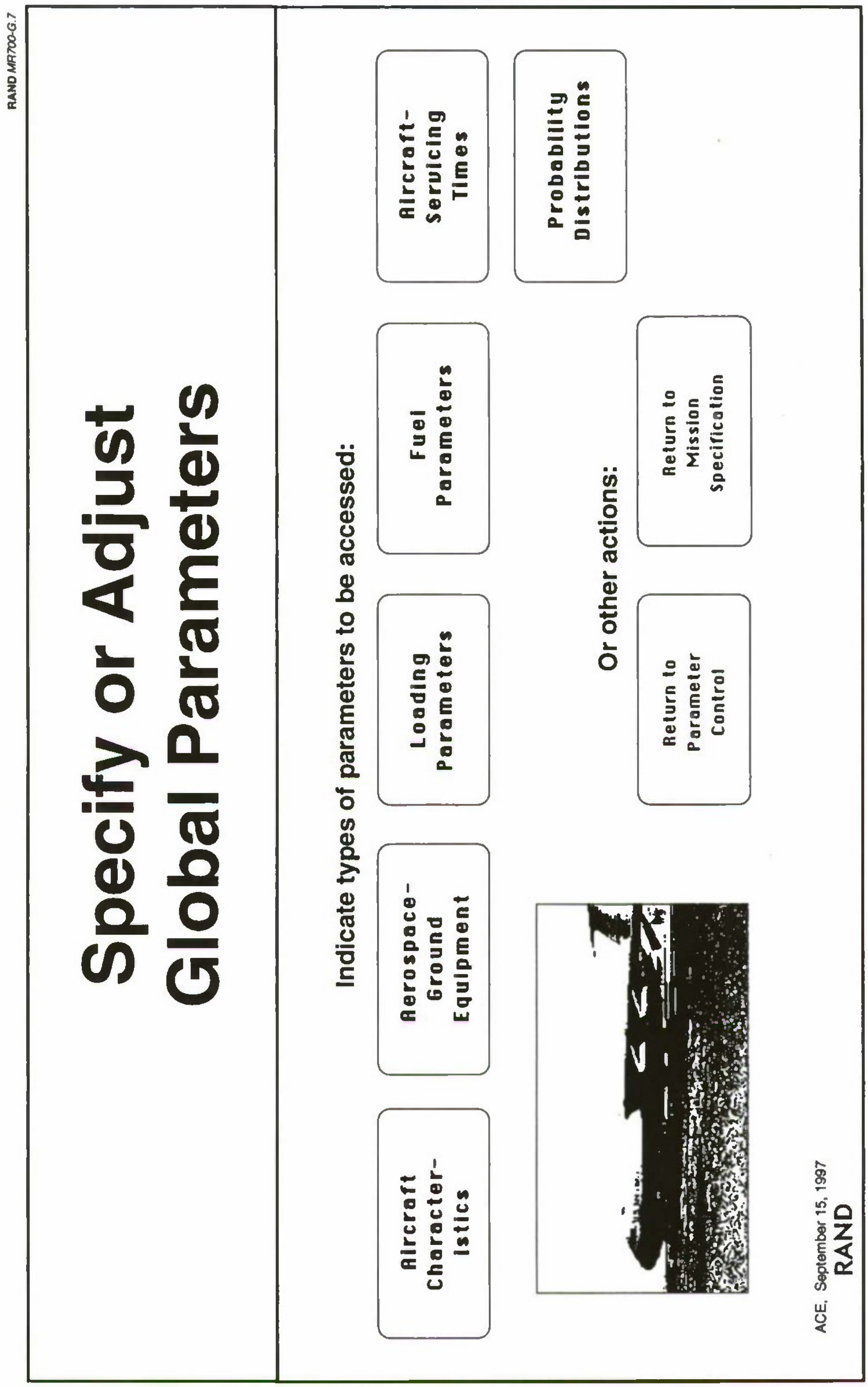


Figure G.7—Global-Parameter Control

RAND MR700-G.8

Aircraft Characteristics

	C-130	C-141	C-5	C-17	KC-10	KC-135	747	Cxx	Cyy
Fuel characteristics									
Number of SPR ports	1	2	2	2	2	1	2		
Maximum on-loading rate (gal/min)	400	900	850	850	2,200	370	2,000		
Capacity (pounds)	62,000	150,000	332,000	182,000	356,000	203,000	370,000		
Loading characteristics									
Maximum number of passengers									
Configured for max cargo	0	0	73	0	0	0	10		
Configured for max pax	91	160	343	102	73	65	400		
Configured for mixed load	23	9	73	51	14	14	10		
Maximum number of pallets									
Configured for max cargo	6	13	36	18	26	7	42		
Configured for max pax	0	0	0	0	16	0	0		
Configured for mixed load	4	12	36	9	23	6	42		

Figure G.8—Aircraft-Related Parameters

RAND MR700-G.9

Times for Aircraft-Servicing Tasks

Item	C-130				C-141			
Aircraft-Servicing	Quick Turn		Full Service		Quick Turn		Full Service	
Tasks	Times	Freqs	Times	Freqs	Times	Freqs	Times	Freqs
Block in	2	1.00	2	1.00	3	1.00	3	1.00
Inspection, post-flight	30	1.00	60	1.00	60	1.00	120	1.00
General servicing	0	1.00	31	1.00	15	1.00	15	1.00
Fueling, pre-fuel	5		5		5		5	
Fueling, fuel transfer								
Fueling, post-fuel	5		5		1		1	
Off-load passengers								
Off-load cargo								
Maintenance	60	0.10	420	0.85	90	0.50	480	0.75
Nitrogen service	0	0.00	40	0.05	60	0.25	60	0.75
On-load cargo								
Oxygen service	60	0.02	70	0.20	60	0.01	60	0.10
On-load passengers								
Inspection, pre-flight			45	1.00			60	1.00
De-icing	60		60		30		30	
Block out	10	1.00	10	1.00	3	1.00	3	1.00

Return to Global-Parameter Control

NOTE: Parameters with lighter background depend only on aircraft type; parameters with shaded background depend on mission and airfield also; black spaces indicate tasks not available for that particular profile.

Figure G.9—Aircraft-Servicing-Task Times

RAND MR700-G.9A

Times for Aircraft-Servicing Tasks

Item	C-5				C-17			
	Quick Turn		Full Service		Quick Turn		Full Service	
Aircraft-Servicing Tasks	Times	Freqs	Times	Freqs	Times	Freqs	Times	Freqs
Block in	5	1.00	5	1.00	5	1.00	5	1.00
Inspection, post-flight	60	1.00	240	1.00	42	1.00	120	1.00
General servicing	30	1.00	30	1.00	20	1.00	30	1.00
Fueling, pre-fuel	5		5		5		5	
Fueling, fuel transfer								
Fueling, post-fuel	5		5		5		5	
Off-load passengers								
Off-load cargo								
Maintenance	150	0.40	240	0.75	60	0.10	60	0.20
Nitrogen service	30	0.30	60	0.60	15	0.10	20	0.10
On-load cargo								
Oxygen service	45	0.05	45	0.20	45	0.15	45	0.38
On-load passengers								
Inspection, pre-flight				1.00			96	1.00
De-icing	60		60		120		120	
Block out	15	1.00	15	1.00	15	1.00	15	1.00

Return to Global-Parameter Control

Screen G.9A—Aircraft-Servicing-Task Times, continued

RAND MR700-G.9B

Times for Aircraft-Servicing Tasks

Item	KC-10				KC-135			
Aircraft-Servicing Tasks	Quick Turn		Full Service		Quick Turn		Full Service	
	Times	Freqs	Times	Freqs	Times	Freqs	Times	Freqs
Block in	5	1.00	5	1.00	15	1.00	15	1.00
Inspection, post-flight	90	1.00	240	1.00	90	1.00	240	1.00
General servicing	30	1.00	30	1.00	30	1.00	30	1.00
Fueling, pre-fuel	5		5		30		30	
Fueling, fuel transfer								
Fueling, post-fuel	5		5		15		15	
Off-load passengers								
Off-load cargo								
Maintenance	140	0.15	420	0.25	240	0.15	420	0.25
Nitrogen service	30	0.25	30	0.25	30	0.25	30	0.25
On-load cargo								
Oxygen service	30	0.20	30	0.20	30	0.20	30	0.20
On-load passengers								
Inspection, pre-flight	[redacted]		210	1.00	[redacted]		210	1.00
De-icing	60		60		20		20	
Block out	20	1.00	20	1.00	20	1.00	20	1.00

Return to Global-Parameter Control

Screen G.9B—Aircraft-Servicing-Task Times, continued

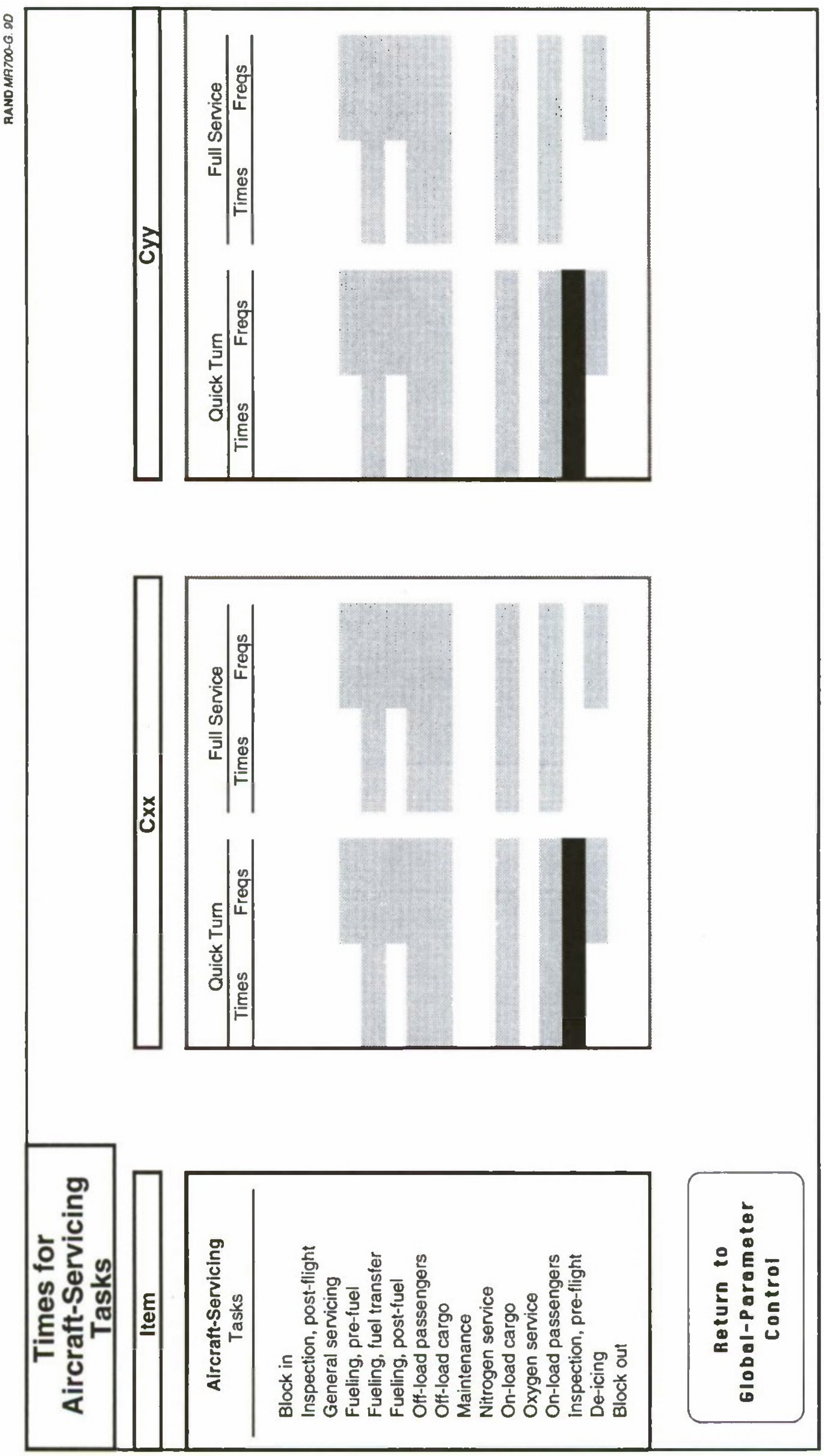
RAND MR700-G.9C

Times for Aircraft-Servicing Tasks

Item	747			
	Quick Turn		Full Service	
Aircraft-Servicing Tasks	Times	Freqs	Times	Freqs
Block in	5	1.00	5	1.00
Inspection, post-flight	60	1.00	60	1.00
General servicing	0	1.00	0	1.00
Fueling, pre-fuel	5		5	
Fueling, fuel transfer				
Fueling, post-fuel	13		13	
Off-load passengers				
Off-load cargo				
Maintenance	120	0.50	210	0.60
Nitrogen service	20	0.50	30	0.70
On-load cargo				
Oxygen service	15	0.10	15	0.25
On-load passengers				
Inspection, pre-flight			120	1.00
De-icing	60		60	
Block out	13	1.00	13	1.00

Return to Global-Parameter Control

Screen G.9C—Aircraft-Servicing-Task Times, continued



Screen G.9D—Aircraft-Servicing-Task Times, continued

RAND MR700-G.10

Minutes Required of Aerospace Ground Equipment per Aircraft Serviced

	Per Operation																Dummies Representing Variable-Time Activities					Default Totals (without dummies)	
	General						Quick Turn					Full Service											
Item	Block in	Pre-fuel	Transfer fuel	Post-fuel	De-ice	Block out	Thru-flight inspection	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Post-flight insp	Pre-flight insp	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Fueling	Pax off-loading	Pax on-loading	Cargo off-loading	Cargo on-loading	Quick Turn	Full Service
C-130																								
Ground-power units	2	5		5	60	8	30				60	30	30			5	336	1	1	1	1	1	170	481
Low-reach service stands											30						336						30	336
Medium-reach service stands								20			30	50		30			336	1	1	1	1	1	50	416
High-reach service stands																							0	0
Oil carts																							0	0
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										60						70							60	70
Liquid-nitrogen carts									15						40								15	40
Liquid-nitrogen trucks																							0	0
De-ice trucks					60																		60	60
Calivars																							0	0
C-141																								
Ground-power units	3				30	3	60				90	120	60				480	1	1	1	1	1	186	696
Low-reach service stands																							0	0
Medium-reach service stands							60	20			90	120	60	15			480	1	1	1	1	1	170	675
High-reach service stands																							0	0
Oil carts																							0	0
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										60						60							60	60
Liquid-nitrogen carts									60						60								60	60
Liquid-nitrogen trucks																							0	0
De-ice trucks					30																		30	30
Calivars					30																		30	30

Return to Global-Parameter Control

Figure G.10—AGE-Use Times

RAND MR700-G.10A

Minutes Required of Aerospace Ground Equipment per Aircraft Serviced

	Per Operation																	Dummies Representing Variable-Time Activities					Default Totals (without dummies)	
	General						Quick Turn					Full Service												
Item	Block in	Pre-fuel	Transfer fuel	Post-fuel	De-ice	Block out	Thru-flight inspection	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Post-flight insp	Pre-flight insp	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Fueling	Pax off-loading	Pax on-loading	Cargo off-loading	Cargo on-loading	Quick Turn	Full Service
C-17																								
Ground-power units	5	5		5			42			5	60	120	96			5	60	1	1	1	1	1	122	296
Low-reach service stands											200						0						200	0
Medium-reach service stands								20			20	60	60	30			30	1	1	1	1	1	40	180
High-reach service stands																							0	0
Oil carts																							0	0
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										45						45							45	45
Liquid-nitrogen carts									15						25								15	25
Liquid-nitrogen trucks																							0	0
De-ice trucks					120																		120	120
Calivars					120																		120	120
KC-10																								
Ground-power units	5	5			60		30				240	120	120				420	1	1	1	1	1	340	730
Low-reach service stands																							0	0
Medium-reach service stands		5									60	60	15				180	1	1	1	1	1	65	260
High-reach service stands	5																						5	5
Oil carts								15						15									15	15
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										30						30							30	30
Liquid-nitrogen carts									30						30								30	30
Liquid-nitrogen trucks																							0	0
De-ice trucks					60																		60	60
Calivars																							0	0
KC-135																								
Ground-power units	30	30			60		30				240	120	120				420	1	1	1	1	1	390	780
Low-reach service stands																							0	0
Medium-reach service stands		30									60	15	10				180	1	1	1	1	1	90	235
High-reach service stands	30																						30	30
Oil carts								15						15									15	15
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										30						30							30	30
Liquid-nitrogen carts									30						30								30	30
Liquid-nitrogen trucks																							0	0
De-ice trucks					20																		20	20
Calivars																							0	0

Return to Global-Parameter Control

Screen G.10A—AGE-Use Times, continued

RANDMR700-G.10B

Minutes Required of Aerospace Ground Equipment per Aircraft Serviced

	Per Operation																	Dummies Representing Variable-Time Activities					Default Totals (without dummies)	
	General						Quick Turn					Full Service												
Item	Block in	Pre-fuel	Transfer fuel	Post-fuel	De-ice	Block out	Thru-flight inspection	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Post-flight insp	Pre-flight insp	General servicing	Nitrogen servicing	Oxygen servicing	Maintenance	Fueling	Pax off-loading	Pax on-loading	Cargo off-loading	Cargo on-loading	Quick Turn	Full Service
747																								
Ground-power units	5	5		13	60		60				120	60					210	1	1	1	1	1	263	353
Low-reach service stands												30											0	30
Medium-reach service stands							30											1	1	1	1	1	30	0
High-reach service stands																							0	0
Oil carts																							0	0
Gaseous-oxygen carts																							0	0
Liquid-oxygen carts										15						15							15	15
Liquid-nitrogen carts									20						20								20	20
Liquid-nitrogen trucks																							0	0
De-ice trucks					60																		60	60
Calivars																							0	0
Cxx																								
Ground-power units																								
Low-reach service stands																								
Medium-reach service stands																								
High-reach service stands																								
Oil carts																								
Gaseous-oxygen carts																								
Liquid-oxygen carts																								
Liquid-nitrogen carts																								
Liquid-nitrogen trucks																								
De-ice trucks																								
Calivars																								
Cyy																								
Ground-power units																								
Low-reach service stands																								
Medium-reach service stands																								
High-reach service stands																								
Oil carts																								
Gaseous-oxygen carts																								
Liquid-oxygen carts																								
Liquid-nitrogen carts																								
Liquid-nitrogen trucks																								
De-ice trucks																								
Calivars																								

Screen G.10B—AGE-Use Times, continued

RANDMR700-G.11

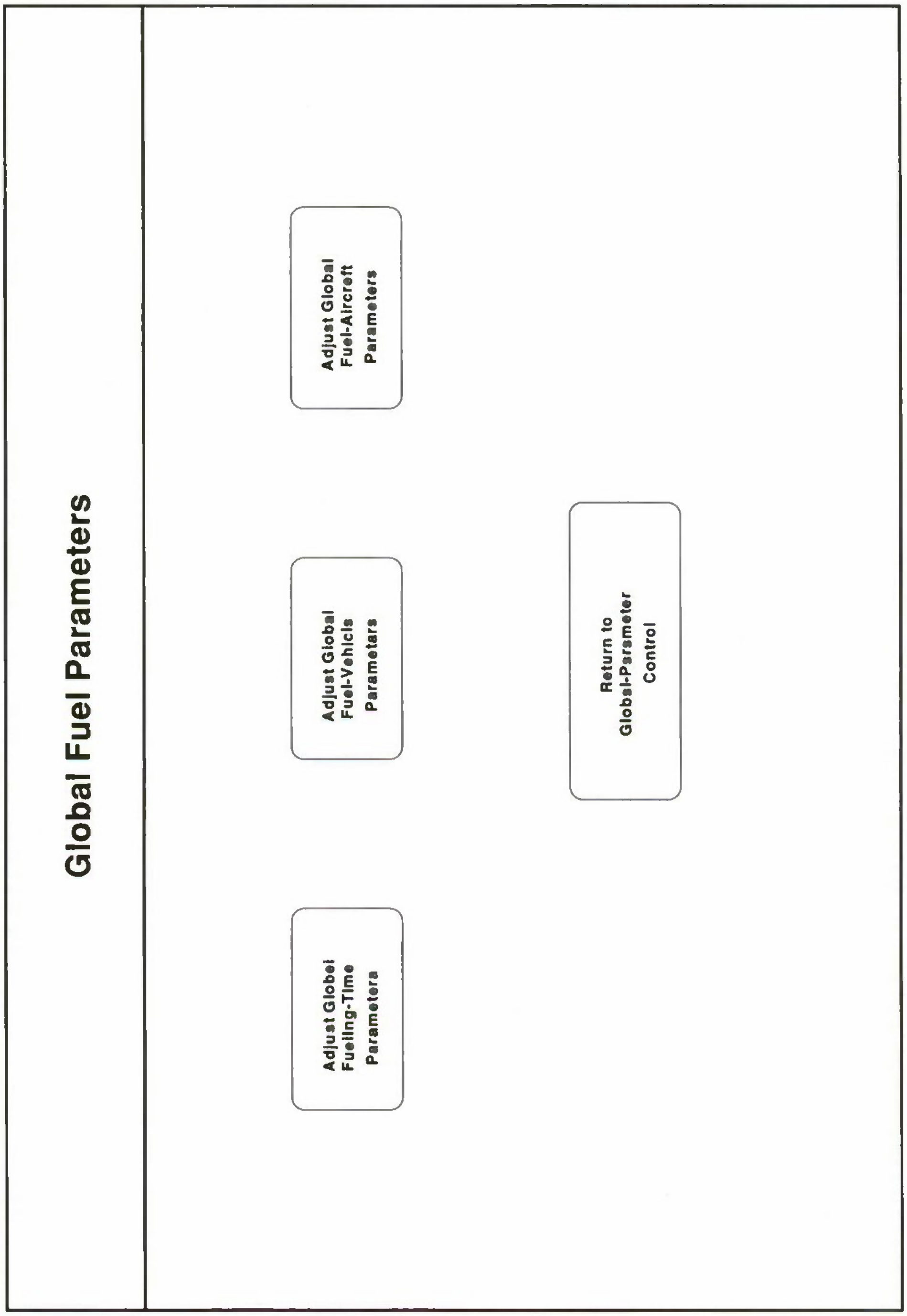


Figure G.11—Fuel-Parameter Control

RANDMR700-G.12

Fuel Characteristics of Aircraft

	C-130	C-141	C-5	C-17	KC-10	KC-135	747	Cxx	Cyy
Fuel characteristics									
Number of SPR ports	1	2	2	2	2	1	2		
Maximum on-loading rate (gal/min)	400	900	850	850	2,200	370	2,000		
Capacity (pounds)	62,000	150,000	332,000	182,000	356,000	203,000	370,000		

Fuel conversion factor, pounds per gallon: 6.70

Figure G.12—Fuel Characteristics of Aircraft

RANDMR700-G.13

Characteristics of Fuel Vehicles

Hydrent service vehicles		R-12	Other 1	Other 2	Other 3	Other 4	Other 5	Other 6	Other 7
maximum flow rete	gellons per minute	750							
Tenker trucks		R-9	R-11	Other 1	Other 2	Other 3	Other 4	Other 5	Other 6
effective speed	miles per hour	5	5						
useble capecity	gellons	4,600	5,800						
mex fuel trensfer (out) rete	gallons per minute	550	550						
mex fuel receive (in) rete	gellons per minute	600	600						

Figure G.13—Characteristics of Fuel Vehicles

RAND MR700-G.14

Times for Fuel Tasks

Activity	Minutes
Hydrant fueling	
Avg HSV move	5
Set up HSV	10
Secure HSV	17
Truck fueling	
Hook up to aircraft	5
Secure from aircraft	15
Withdraw from aircraft	5
Fill-stand use	
Hookup time	0
Unhook time	0

Return to Global-Parameter Control

Screen G.14—Times for Fueling Tasks

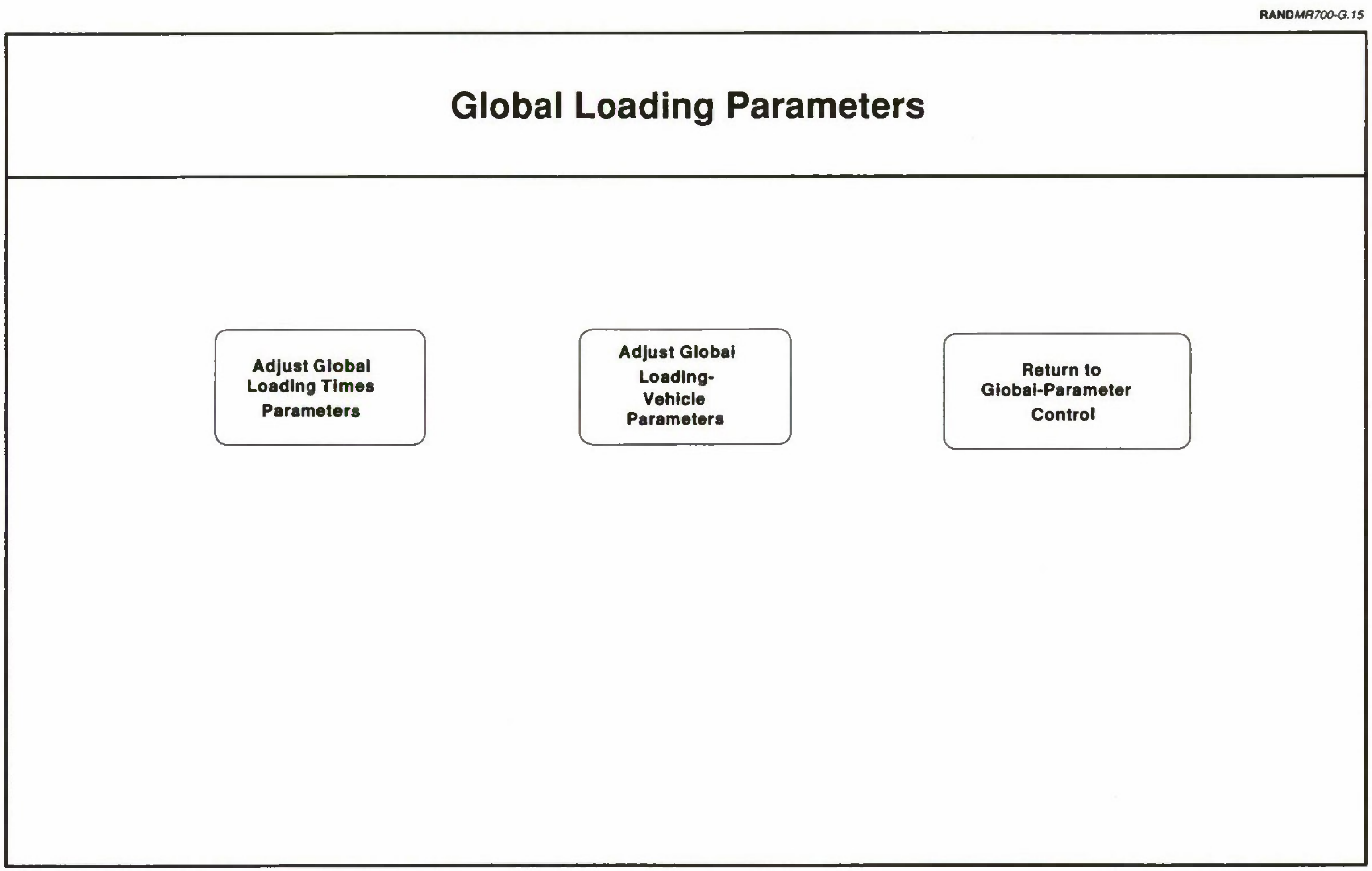


Figure G.15—Loading-Parameter Control

RANDMR700-G.16

Characteristics of Standard Loading Vehicles

Buses		Standard			
Availability	minutes per day	1,200			
Usable capacity	persons with gear	30			
Effective speed	miles per hour	15			
Pallet transporters		25k-loader	40k-loader	60k-loader	Forklift
Availability	minutes per day	115	141	1,200	172
Usable capacity	pallets	3	5	6	1
Effective speed	miles per hour	15	15	15	15
Wide-Body Elevator Loaders		Cochran	Wilson	TA-40	60k-loader Proxy
Availability	minutes per day	115	115	115	1,200
Usable capacity	pallets	2	2	2	6
Effective speed	miles per hour	2.50	2.50	15	15
Trucks		40-foot Equivalent			
Availability	minutes per day	1,200			
Usable capacity	pallets	4			
Effective speed	miles per hour	20			

Figure G.16—Characteristics of Loading Vehicles

RANDMR700-G.17

Times for Loading Tasks

Configuration Times

Activity	C-130 Minutes	C-141 Minutes
Sat up for loading work	6	6
Sat up for working pallats	5	5
Sat up for working passangars	6	6
Sat up for working NPC	6	6
Standdown from loading work	6	6

Handling Nonpalletized Cargo

Item	C-130 Minutas to Handla Full Load			C-141 Minutas to Handla Full Load		
	HMMWVs	C-5 Eng	Helicopters	HMMWVs	C-5 Eng	Helicopters
Off-load	30	n/a	n/a	60	n/a	n/a
On-load	45	n/a	n/a	90	n/a	n/a

Loading Times for Passengers and Pallets

Item	C-130 Minutas to Load		C-141 Minutes to Load	
	Standard Bus	Standard Pallet	Standard Bus	Standard Pallet
Off-load				
Aircraft to transport	10	1.00	10	1.00
Transport to terminal	5	1.00	5	1.00
On-load				
Terminal to transport	7	1.00	7	1.00
Transport to aircraft	10	1.30	10	1.00

NOTES: Bus estimates are for a standard busload; pallet estimataa are for aach standard pallat.
n/a = not applicable.

Figure G.17—Loading-Task Times

RANDMR700-G.17A

Times for Loading Tasks

Item	C-5	C-17

Configuration Times

Activity	C-5 Minutes	C-17 Minutes
Sat up for loading work	18	6
Sat up for working pallets	5	5
Set up for working passengers	18	6
Set up for working NPC	18	6
Standdown from loading work	18	6

Handling Nonpalletized Cargo

	C-5 Minutes to Handle Full Load			C-17 Minutas to Handle Full Load		
	HMMWVs	C-5 Eng	Helicopters	HMMWVs	C-5 Eng	Helicopters
Off-load	120	180	240	45	150	150
On-load	180	240	240	75	150	150

Loading Times for Pessengars and Pallets

	C-5 Minutas to Load		C-17 Minutes to Load	
	Standard Bus	Standard Pallat	Standard Bus	Standard Pallet
Off-load				
Aircraft to transport	10	1.00	10	1.00
Transport to tarminal	5	1.00	5	1.00
On-load				
Tarminal to transport	7	1.00	7	1.00
Transport to aircraft	10	1.70	10	1.00

NOTE: Bus estimatas are for a standard busload; pallet astimatas are for aach standard pallet.

Screen G.17A—Loading-TaskTimes, continued

RANDMR700-G.17B

Times for Loading Tasks

Configuration Times

Activity	KC-10 Minutes	KC-135 Minutes
Set up for loading work	5	5
Set up for working pallets	5	5
Set up for working passengers	5	5
Set up for working NPC	5	5
Standdown from loading work	5	5

Handling Nonpalletized Cargo

Item	KC-10 Minutes to Handle Full Load			KC-135 Minutes to Handle Full Load		
	HMMWVs	C-5 Eng	Helicopters	HMMWVs	C-5 Eng	Helicopters
Off-load	n/a	n/a	n/a	n/a	n/a	n/a
On-load	n/a	n/a	n/a	n/a	n/a	n/a

Loading Times for Passengers and Pallets

Item	KC-10 Minutes to Load		KC-135 Minutes to Load	
	Standard Bus	Standard Pallet	Standard Bus	Standard Pallet
Off-load				
Aircraft to transport	10	1.50	10	1.50
Transport to terminal	5	1.00	5	1.00
On-load				
Terminal to transport	7	1.00	7	1.00
Transport to aircraft	10	1.50	10	2.70

NOTES: Bus estimates are for a standard busload; pallet estimates are for each standard pallet.
n/a = not applicable.

Screen G.17B—Loading-TaskTimes, continued

RANDMR700-G.17C

Times for Loading Tasks

Item	747

Configuration Times

Activity	Minutes
Set up for loading work	0
Set up for working pallets	0
Set up for working passengers	0
Set up for working NPC	0
Standdown from loading work	0

Handling Nonpalletized Cargo

	Minutes to Handle Full Load		
	HMMWVs	C-5 Eng	Helicopters
Off-load	n/a	n/a	n/a
On-load	n/a	n/a	n/a

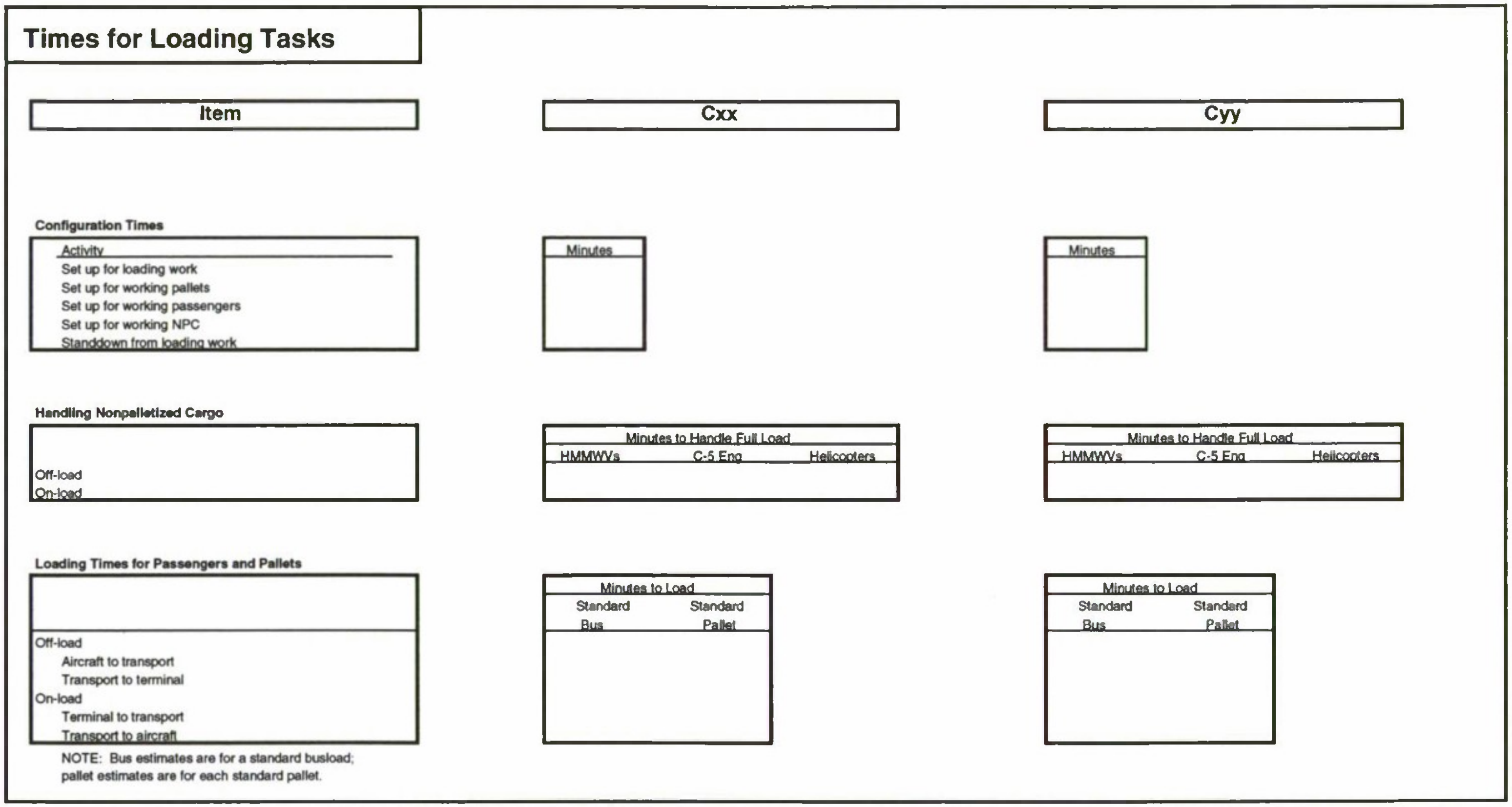
Loading Times for Passengers and Pallets

	Minutes to Load	
	Standard Bus	Standard Pallet
Off-load		
Aircraft to transport	10	3.00
Transport to terminal	5	1.00
On-load		
Terminal to transport	7	1.00
Transport to aircraft	10	3.00

NOTES: Bus estimates are for a standard busload; pallet estimates are for each standard pallet.
n/a = not applicable.

Screen G.17C—Loading-TaskTimes, continued

RAND MR700-G.17D



Screen G.17D—Loading-TaskTimes, continued

RAND MR700-G.18

Distribution of Nitrogen Servicing Times

Distribution of Servicing Times (hours)

	Check Sum
C-130	0.0000
C-141	0.0000
C-5	0.0000
C-17	0.0000
KC-10	0.0000
KC-135	0.0000
747	0.0000
Cxx	0.0000
Cyy	0.0000

Quick Turn		Full Service	
Times	Freqs	Times	Freqs
0	0.00	40	0.05
60	0.25	60	0.75
30	0.30	60	0.60
15	0.10	20	0.10
30	0.25	30	0.25
30	0.25	30	0.25
20	0.50	30	0.70

Distribution of Oxygen Servicing Times

Distribution of Servicing Times (hours)

	Check Sum
C-130	0.0000
C-141	0.0000
C-5	0.0000
C-17	0.0000
KC-10	0.0000
KC-135	0.0000
747	0.0000
Cxx	0.0000
Cyy	0.0000

Quick Turn		Full Service	
Times	Freqs	Times	Freqs
60	0.02	70	0.20
60	0.01	60	0.10
45	0.05	45	0.20
45	0.15	45	0.38
30	0.20	30	0.20
30	0.20	30	0.20
15	0.10	15	0.25

Return to Global-Parameter Control

Figure G.18—Distribution of Servicing Times

RANDMR700-G.18A

Distribution of Repair Times

	Distribution of Failures by Time to Fix (hours)										Quick Turn		Full Service	
	0 - 4	4 - 8	8 - 12	12 - 16	16 - 24	24 - 48	48 - 72	> 72	Check					
	4	8	12	16	24	48	72	96	Sum		Times	Freqs	Times	Freqs
C-130											60	0.10	420	0.85
C-141	0.4064	0.2269	0.1536	0.0809	0.0611	0.0479	0.0143	0.0088	1.0000		90	0.50	480	0.75
C-5	0.2488	0.2179	0.1221	0.1175	0.0943	0.1391	0.0294	0.0309	1.0000		150	0.40	240	0.75
C-17	0.3966	0.1207	0.0345	0.0345	0.1207	0.1552	0.1034	0.0345	1.0000		60	0.10	60	0.20
KC-10									0.0000		140	0.15	420	0.25
KC-135									0.0000		240	0.15	420	0.25
747									0.0000		120	0.50	210	0.60
Cxx									0.0000					
Cyy									0.0000					

Distribution of De-icing Times

	Distribution of De-icing Times (hours)	Check Sum		Quick Turn Times	Quick Turn Freqs	Full Service Times	Full Service Freqs
C-130		0.0000		60	n/s	60	n/s
C-141		0.0000		30	n/s	30	n/s
C-5		0.0000		60	n/s	60	n/s
C-17		0.0000		120	n/s	120	n/s
KC-10		0.0000		60	n/s	60	n/s
KC-135		0.0000		20	n/s	20	n/s
747		0.0000		60	n/s	60	n/s
Cxx		0.0000			n/s		n/s
Cyy		0.0000			n/s		n/s

Figure G.18A—Distribution of Servicing Times, continued

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